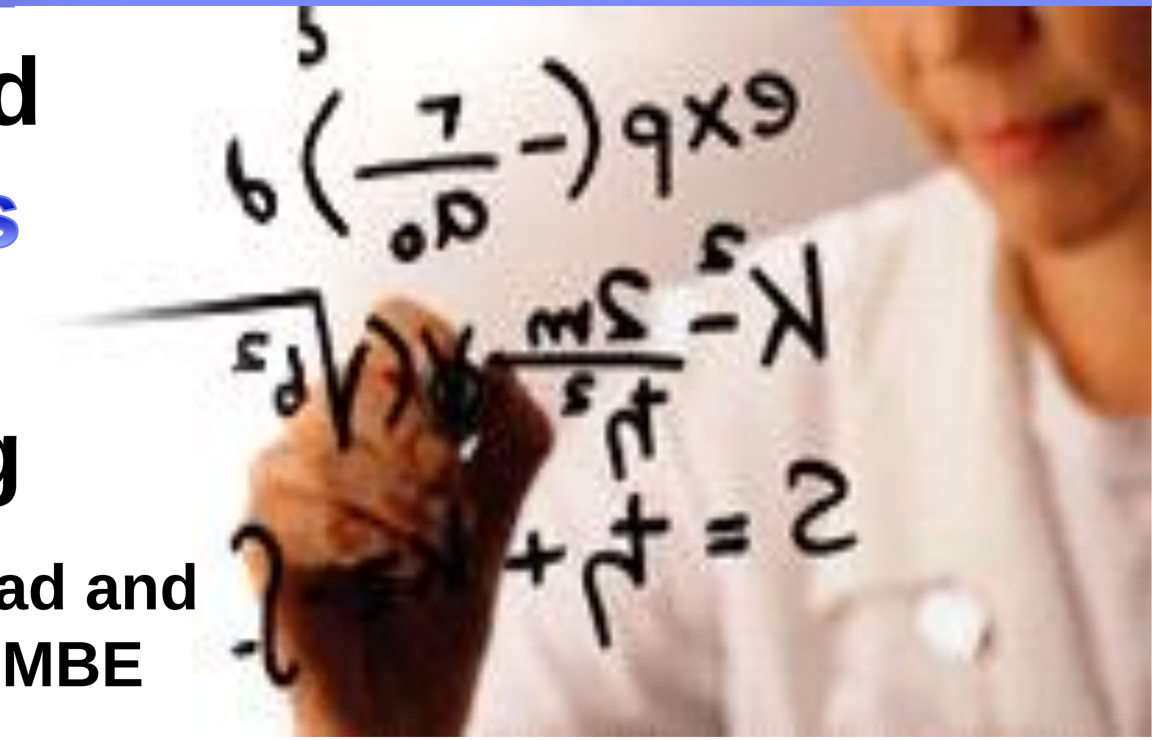
IBM Research – Haifa Labs

Model Based Continuous ~~Systems~~ Engineering

How to Reduce Overhead and Increase the Value of MBE



Michael Masin
Systems & IoT Engineering

Thanks to
Systems & IoT Engineering group (… and others)





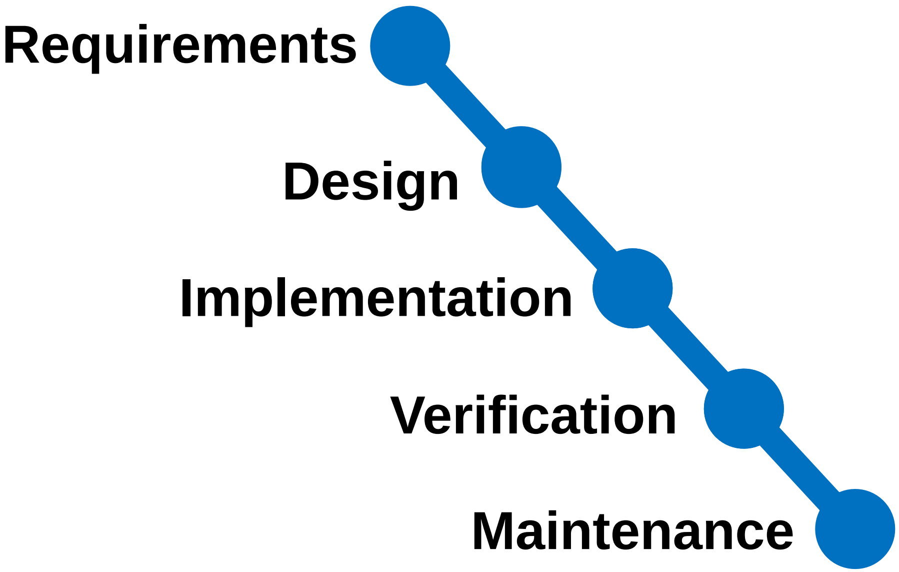





Agenda

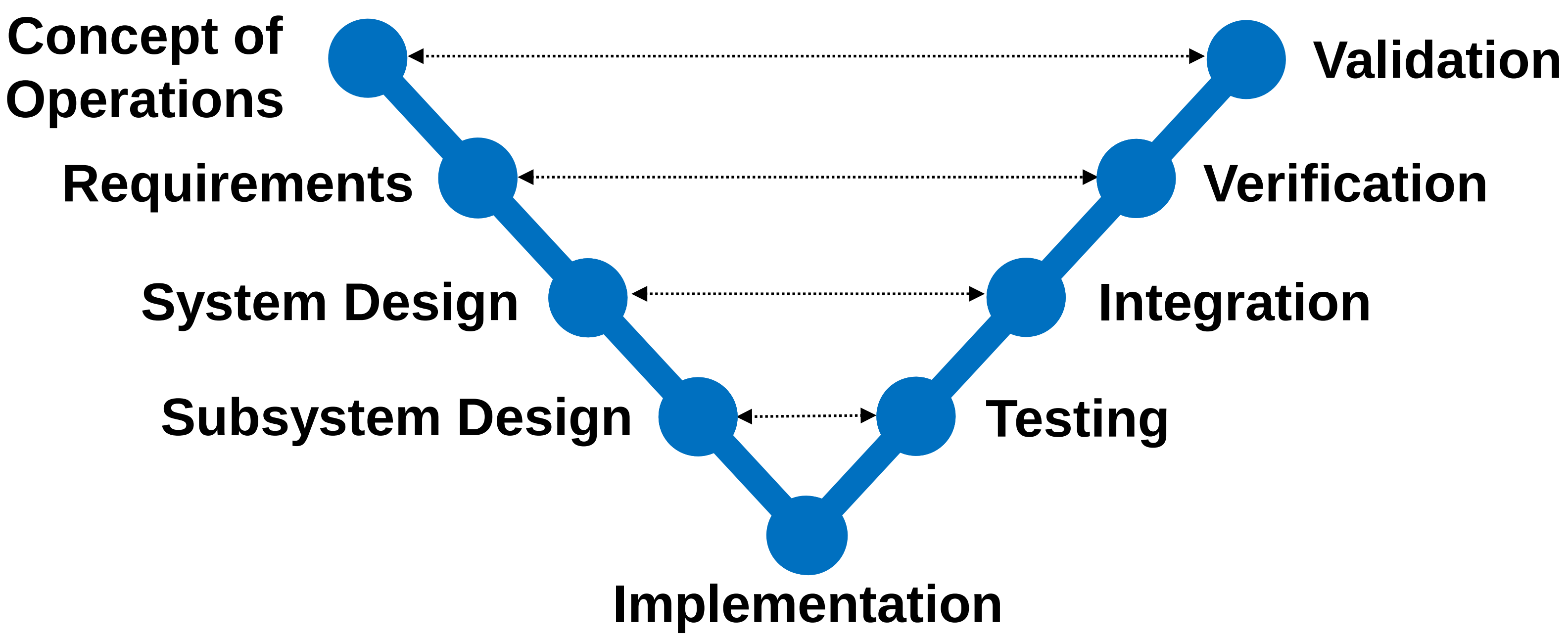
- **From SE to MBCE**
- AOW background
- PORTALS
- FAME
- EMI
- DANSE
- Summary

Waterfall Model (Benington 1956, Royce 1970)



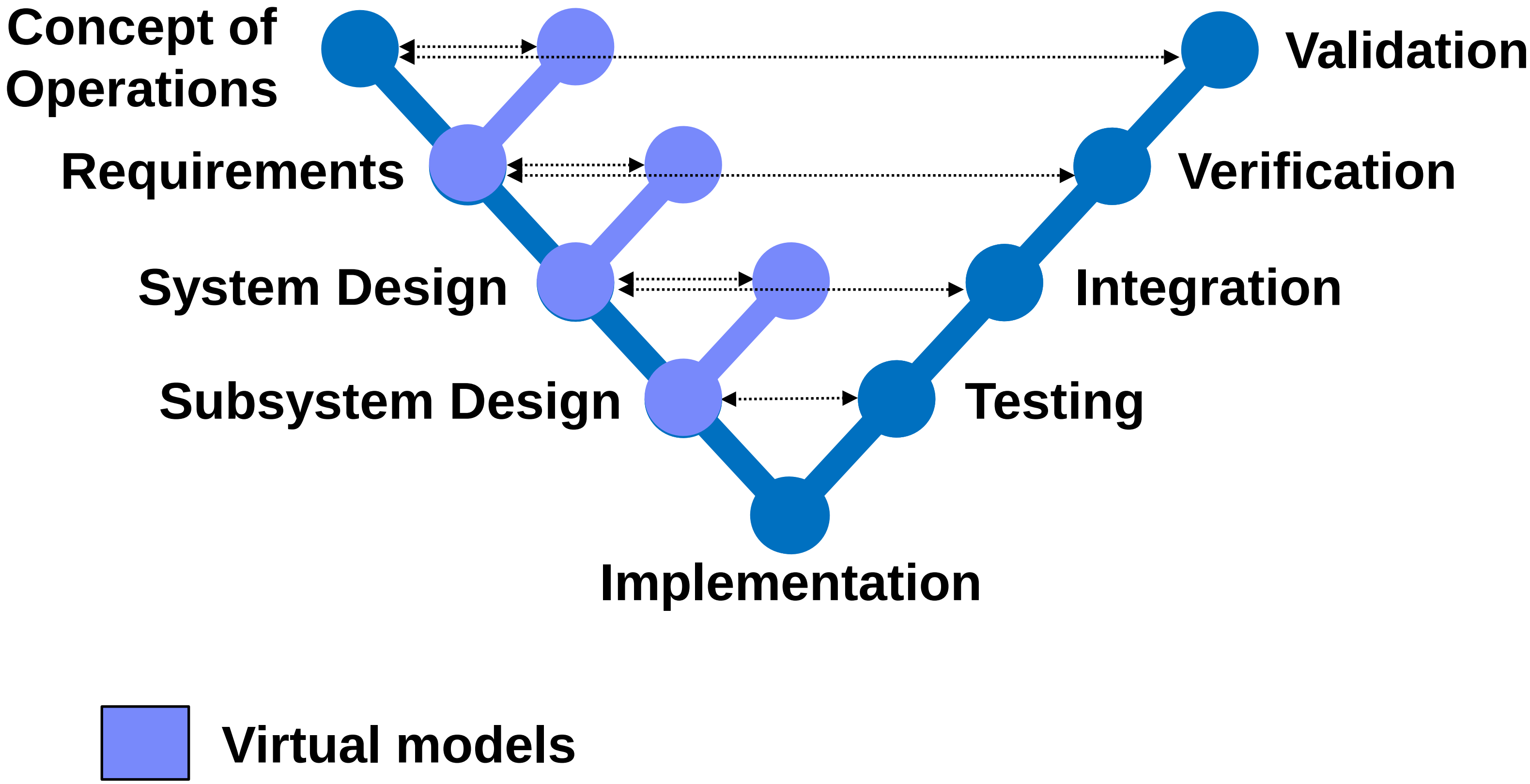
Start of SE

V Model (~1980s)



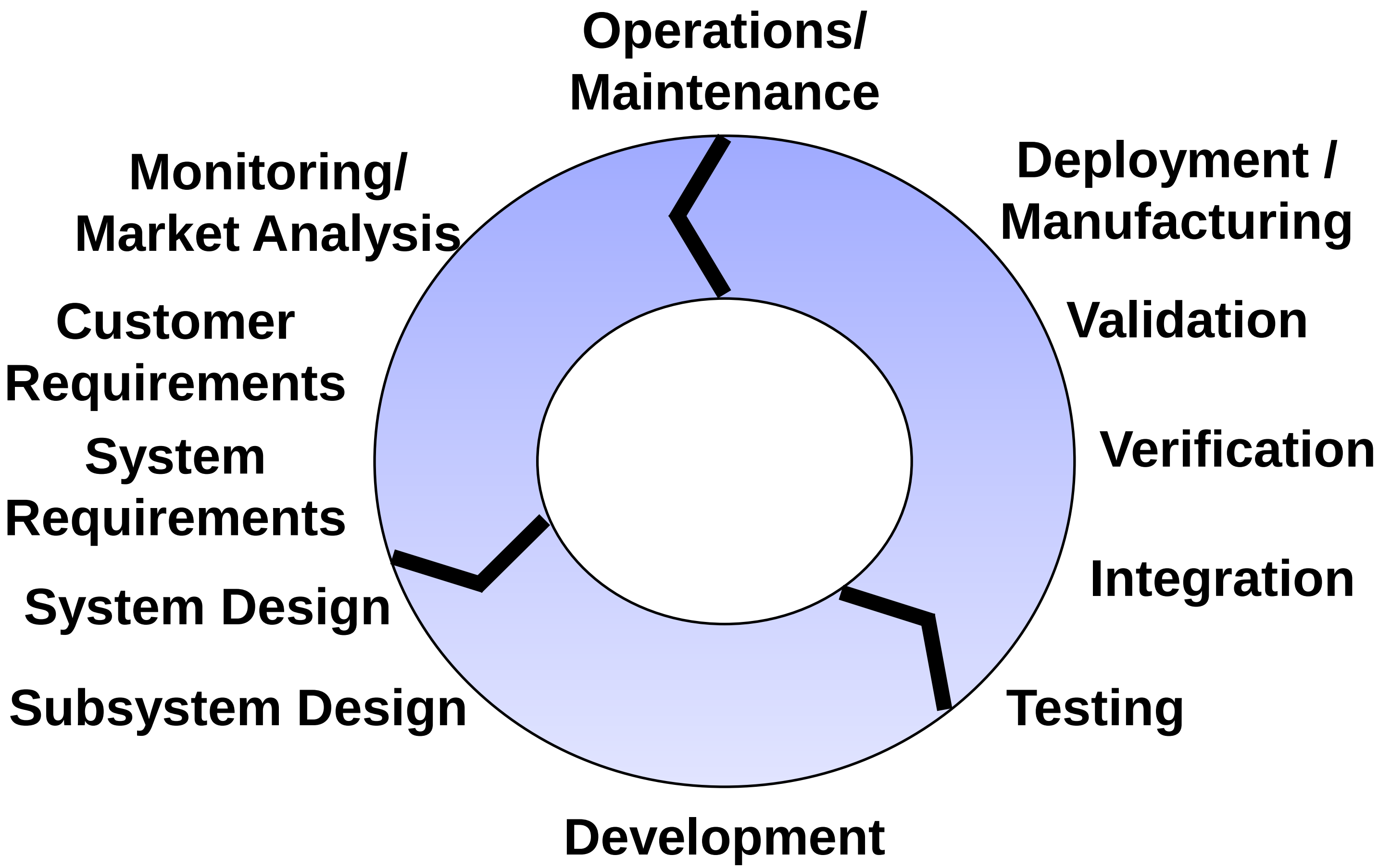
SE as we know today

W Model (recent 5-10 years)



MBSE

Model Based Continuous Engineering (MBCE)



Use models to create models
Virtual / real environment

Agenda

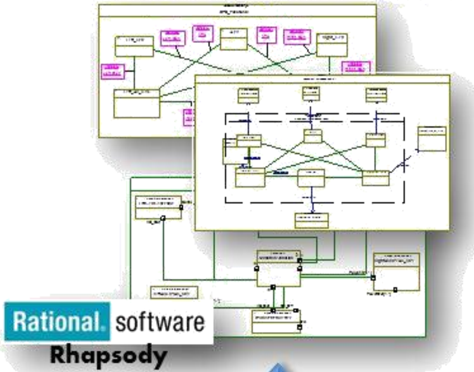
- From SE to MBCE
- **AOW background**
- PORTALS
- FAME
- EMI
- DANSE
- Summary

Architectural Design

- System Complexity is increasing – manual decisions no longer possible
- Solution approaches:
  - Levels of Abstraction
    - Mapping from Layer *i* (Requirements) to Layer *i*+1 (Architecture)
  - Separation of concerns
    - Multiple viewpoints: functional, technical, geometrical, safety, timing, …
    - Modeling Viewpoints vs. Analysis Viewpoints
    - Independent asynchronous development
  - Tools
    - Modeling
      - Component Based Design
    - Analysis
      - Domain specific tools
      - Extension of modeling tools
      - Black box integration
      - Custom optimization modeling

IBM’s Architecture Optimization Workbench Concept

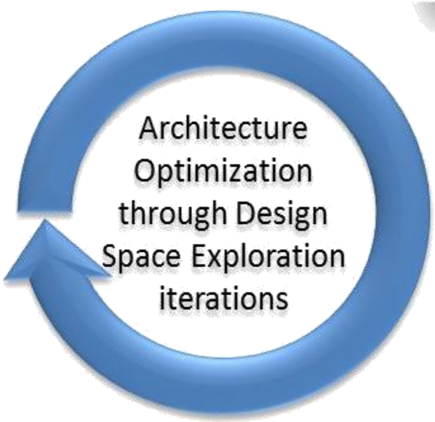
1. Describe system through different SysML views, including design alternatives, constraints and goals



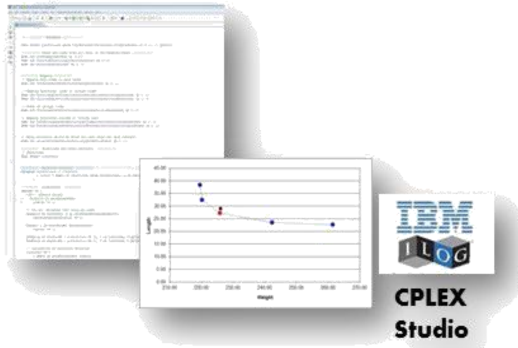
2. Derived Data Schema for Input and output structures

id	name	guid		variants
1	Junction	GUID	e1eb1581-c487-4be2-9fd6-8ce56a53b2ea	Cat Junction
3	Relay	GUID	8feb223d-5bc6-40d6-b173-46b5ff3d7e58	Cat Relay

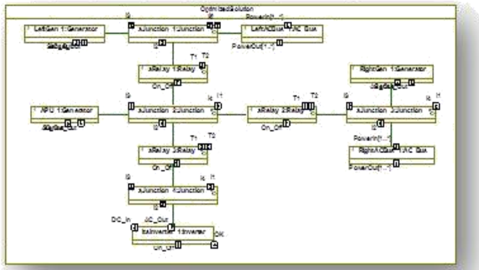
id	name	guid		typeid	type name	variants	base	from	to
23	Placeholder	GUID	[illegible]	23	Placeholder	inv Placeholder			
16	RightGen	GUID	[illegible]	10	Generator	inv RightGen			
33	tsPlaceholder	GUID	[illegible]	23	Placeholder	inv tsPlaceholder	[illegible]		
18	RightACBus	GUID	[illegible]	13	AC_Bus	inv RightACBus			
20	APU	GUID	[illegible]	10	Generator	inv APU			
8	tsInverter	GUID	[illegible]	7	Inverter	inv tsInverter			
24	tsRelayPlaceholder	GUID	[illegible]	22	RelayPlaceholder	inv tsRelayPlaceholder	[illegible]		
27	tsJunctionPlaceholder	GUID	[illegible]	26	JunctionPlaceholder	inv tsJunctionPlaceholder	[illegible]		
11	LeftGen	GUID	[illegible]	10	Generator	inv LeftGen			
14	LeftACBus	GUID	[illegible]	13	AC_Bus	inv LeftACBus			
32	LinkPlaceholders	GUID	[illegible]			inv LinkPlaceholders		[illegible]	[illegible]



3. Automatic translation(via an interchange format) into Optimization solver



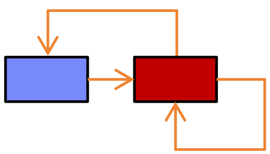
4. Optimized architecture back annotated to SysML model



Concise modeling = SysML views + Data

SysML view

Pattern



Catalog Data

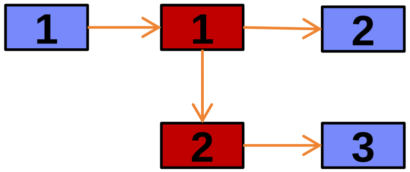
Table1

Table2

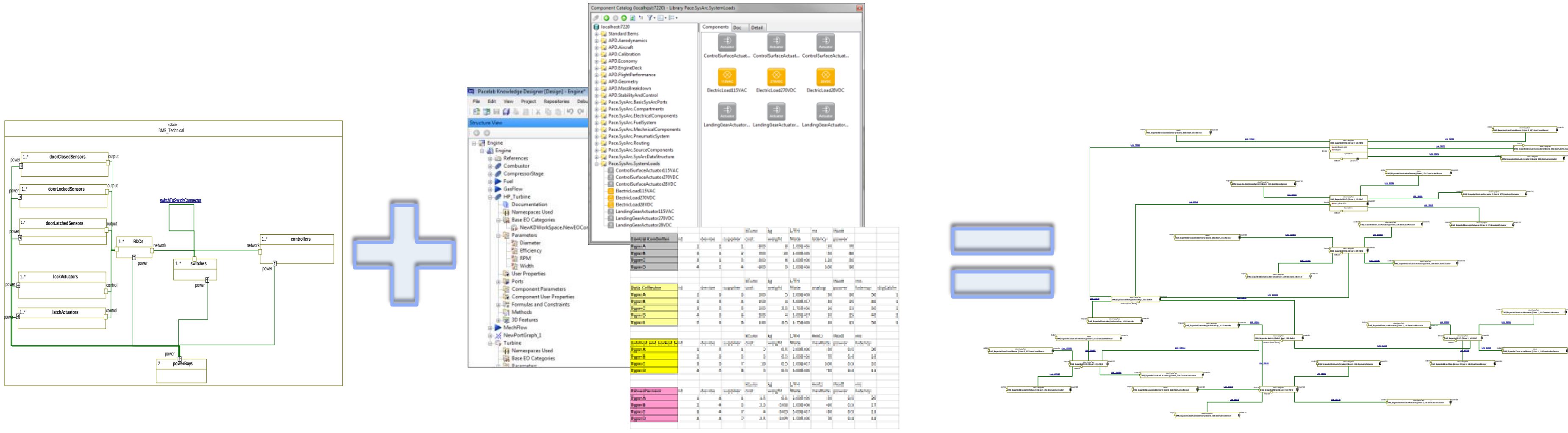
Table3 - connectors

Optimization & Back annotation

Resulting SysML view



AOW uses Concise Modeling



- **Large systems architectures are difficult to model**
  - Lots of elements and details
  - Time consuming
  - Error prone
- **Concise Modeling – SysML models combined with tabular data**
  - SysML depicts the system composition rules
  - Tables contain instantiations (catalogs of types and inventories of parts)
- **Component libraries**
- **Optimization fills missing attribute values or inventory tables**

Semantic Middleware (SEMI)

- **Paradigm shift**: from *Classification-by-Containment* to ***Classification-by-Property***
  - suggested by Parsons and Wand (2000) for information management
  - define *things* that possess properties
    - hierarchy of properties
  - no a-priory classification, open world assumption
  - *classes* are defined by set of properties
    - things could belong to many classes
  - *instance, class* and *property bases*
- **Main API**: **AttributeSet**(A), where A is a set of attributes
  - returns instances that have all attributes in set A
  - e.g., **AttributeSet**({Cost}) returns all instances that have attribute "Cost"
- **Domain specific ontologies**
- **Design Space Exploration (DSE) ontology**
  - Attributes could be either variables or parameters
  - *isSelected*

Pluggable Analysis Viewpoints

- **from**

$$totalCost = \sum_{j \in SensorTypes} \sum_{i \in Sensors} SensorType[j].Cost \cdot sensor[i][j] + \cdots$$
$$+ \sum_{j \in SwitchTypes} \sum_{i \in Switches} SwitchType[j].Cost \cdot switch[i][j]$$

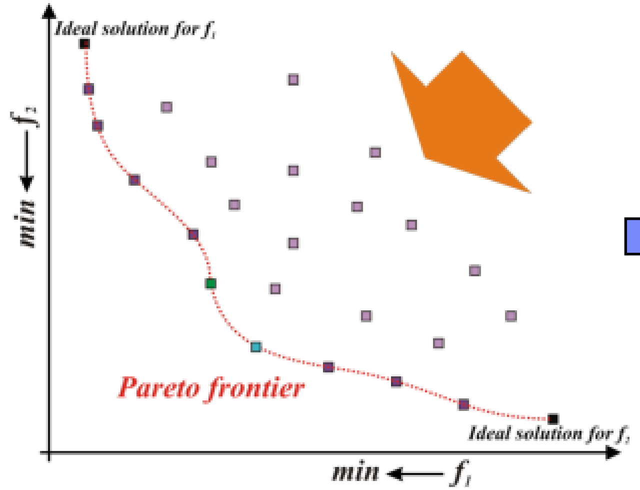
- **to**

$$totalCost(i) = \sum_{j \in \mathbf{AttributeSet}(\{\mathrm{Cost}\})} isSelected(j) \cdot Cost(j) \quad \forall\, i \in \mathbf{AttributeSet}(\mathrm{totalCost})$$

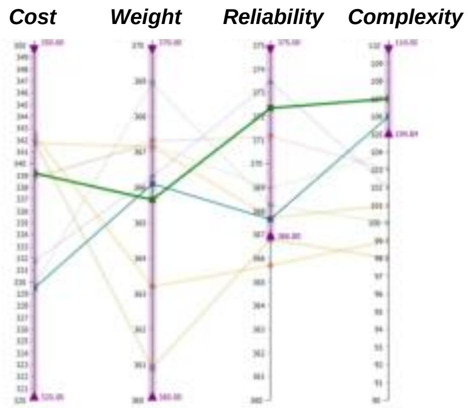
AOW allows for Multi Objective Optimization

Optimization Problem Formulation (CPLEX)

Calculation of Efficient Frontier

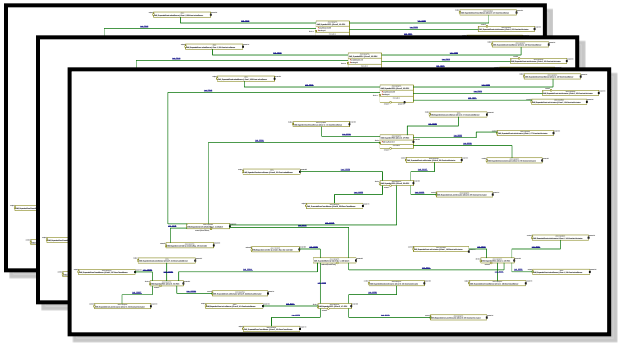


Multi Objective visualization



Selection of desired frontier

Architectures on efficient frontier



Next iteration

AOW Vision: Accelerate Smarter Architectural Decisions

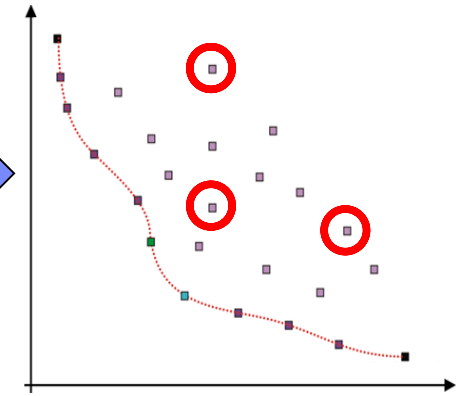
NOW

Definition of design alternatives

Analysis

Review

- Manual process
  - Mostly based on individual undocumented experience
  - Lots of reuse of previous designs
  - No assurance for solution optimality
  - Each additional design – linear effort
- No formal capture of designs
  - Modeling for specific analysis types



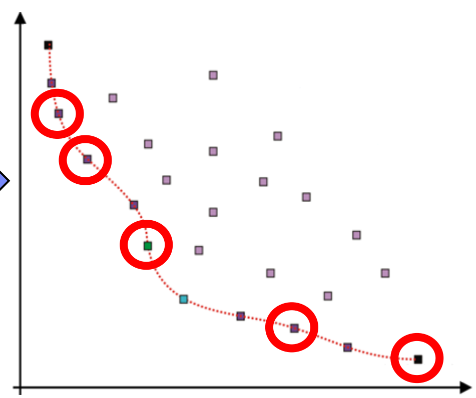
time

With AOW

Architectural template definition

Review

Automated Design Space Exploration



- Faster design
- Smarter designs
- Transparency, traceability
- Knowledge capture and reuse
- Optimization Capabilities in the hands of Architects

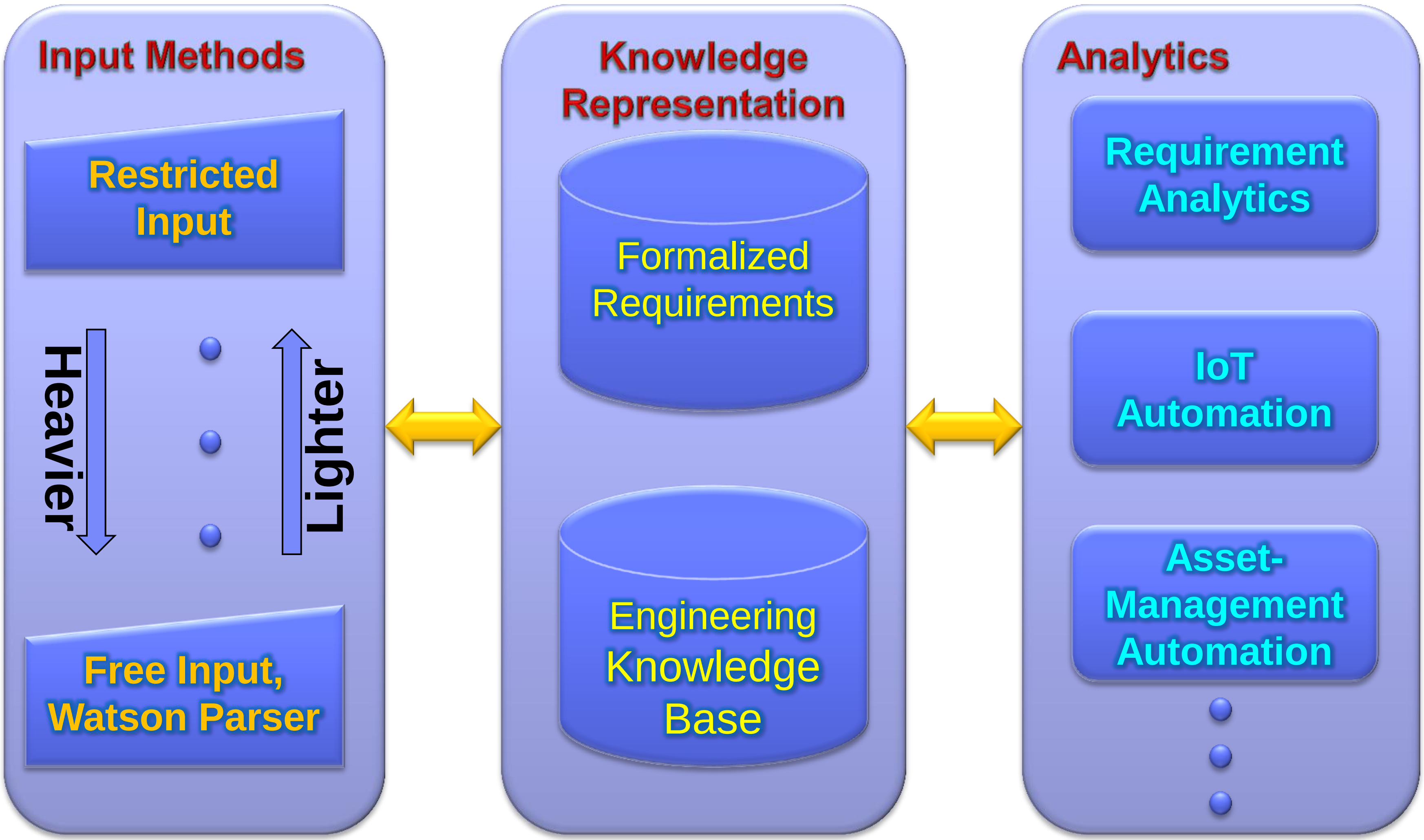
Agenda

- From SE to MBCE
- AOW background
- **PORTALS**
- FAME
- EMI
- DANSE
- Summary

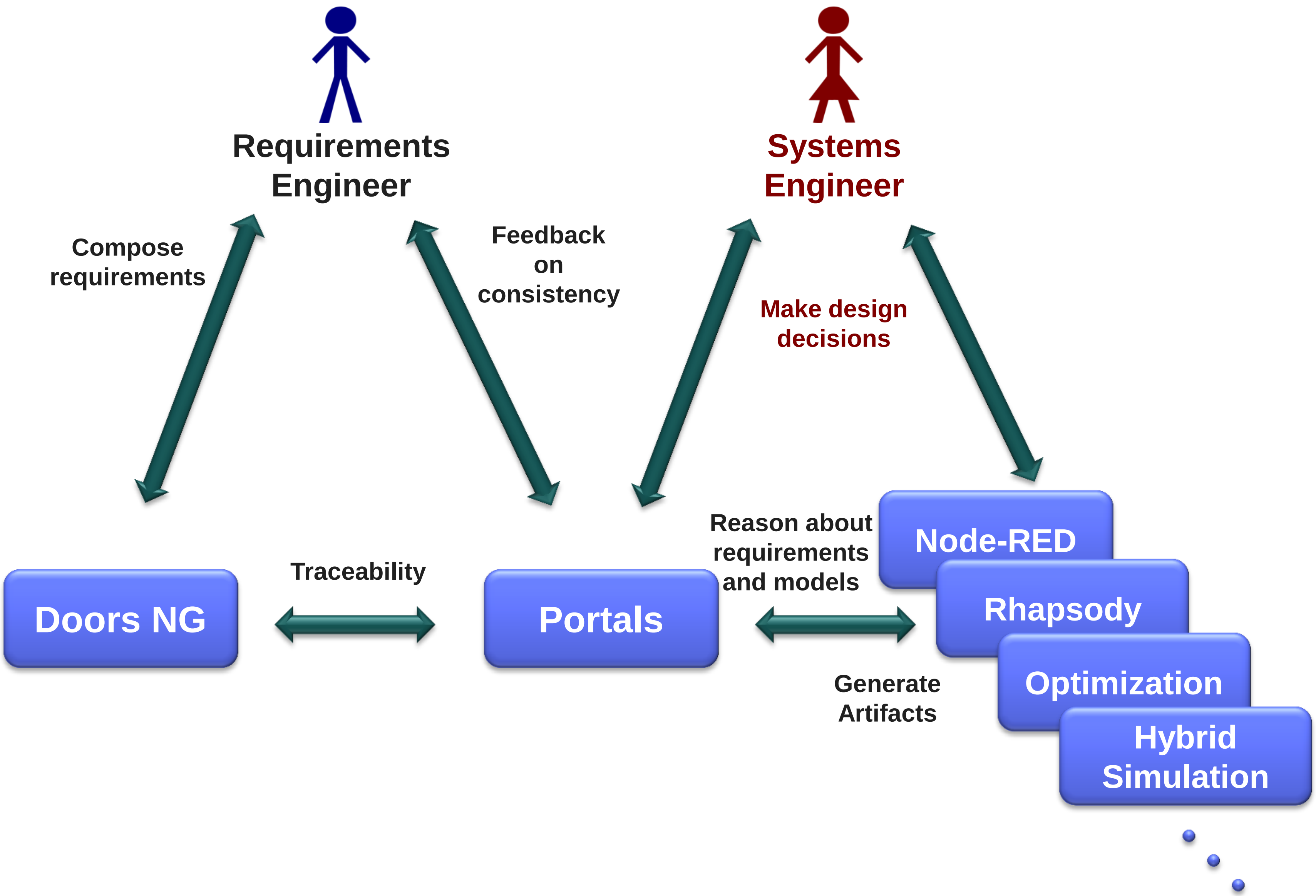
PORTALS

- PORTALS is a research project whose goal is
  - to create tools to assist requirements engineers in incrementally raising the formalization level of system requirements, and
  - to use formalized requirements to
    - provide feedback on the quality of the requirements (e.g., identifying omissions and contradictions), and
    - create downstream artifacts (e.g., models, monitors, tests, code)

PORTALS Architecture

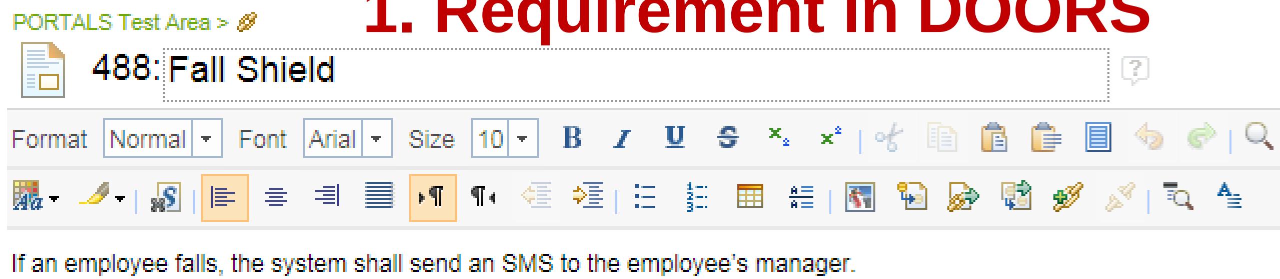


Personas and interactions



Scenario 1: WorkRight Fall Shield

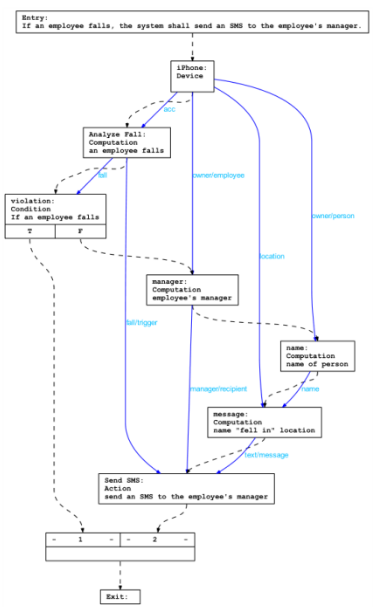
1. Requirement in DOORS



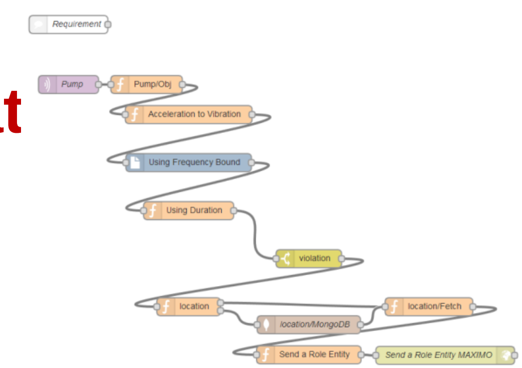
2. Paraphrase by PORTALS

if "an employee" falls then "the system" shall send [an abstract entity] "an SMS" (direction) "manager" of "the employee's"

3. Process Model

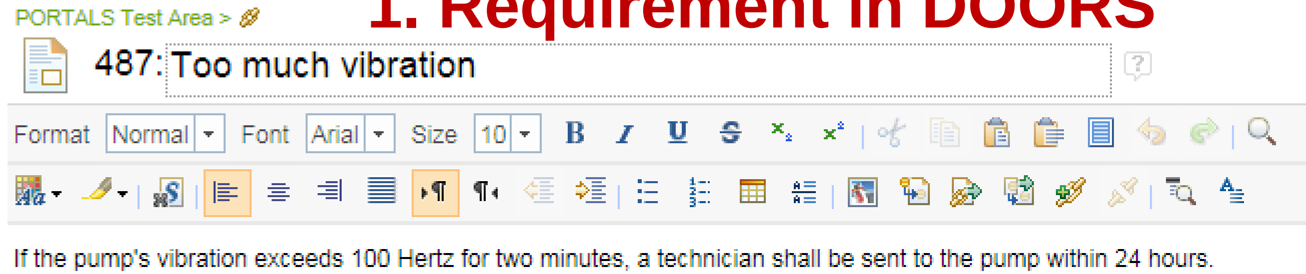


4. Implementation in Node-RED



Scenario 2: IoT Pump

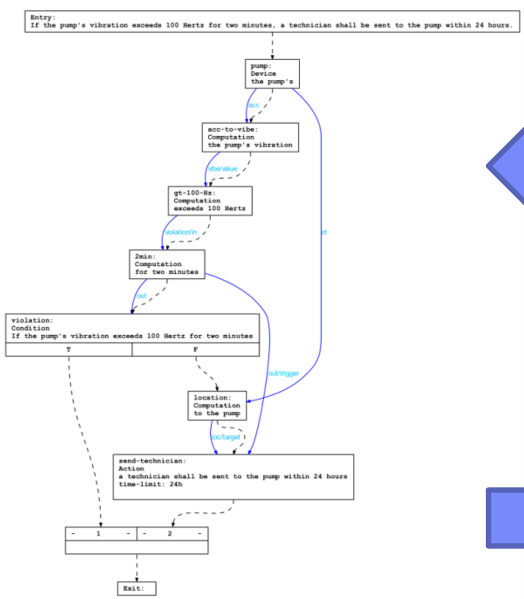
1. Requirement in DOORS



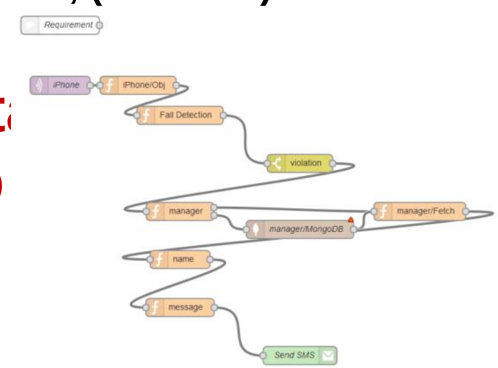
2. Paraphrase by PORTALS

if "vibration" of "the pump's" is greater than 100 Hz (duration) 2 min then "?" shall send [a role entity] "a technician" (duration) 24 hr; (direction) "the pump"

3. Process Model



4. Implementation in Node-RED



Engineering Knowledge Base: WorkRight Catalog

Events

Overexertion
- Heart Rate
- Body Temperature
- Sweat & Tears

Fall Detection
- Accelerometer
- Radar

Devices / Systems

iPhone
- Accelerometer
- Orientation
- Vibration
- Send SMS
- Device ID
- Owner ID

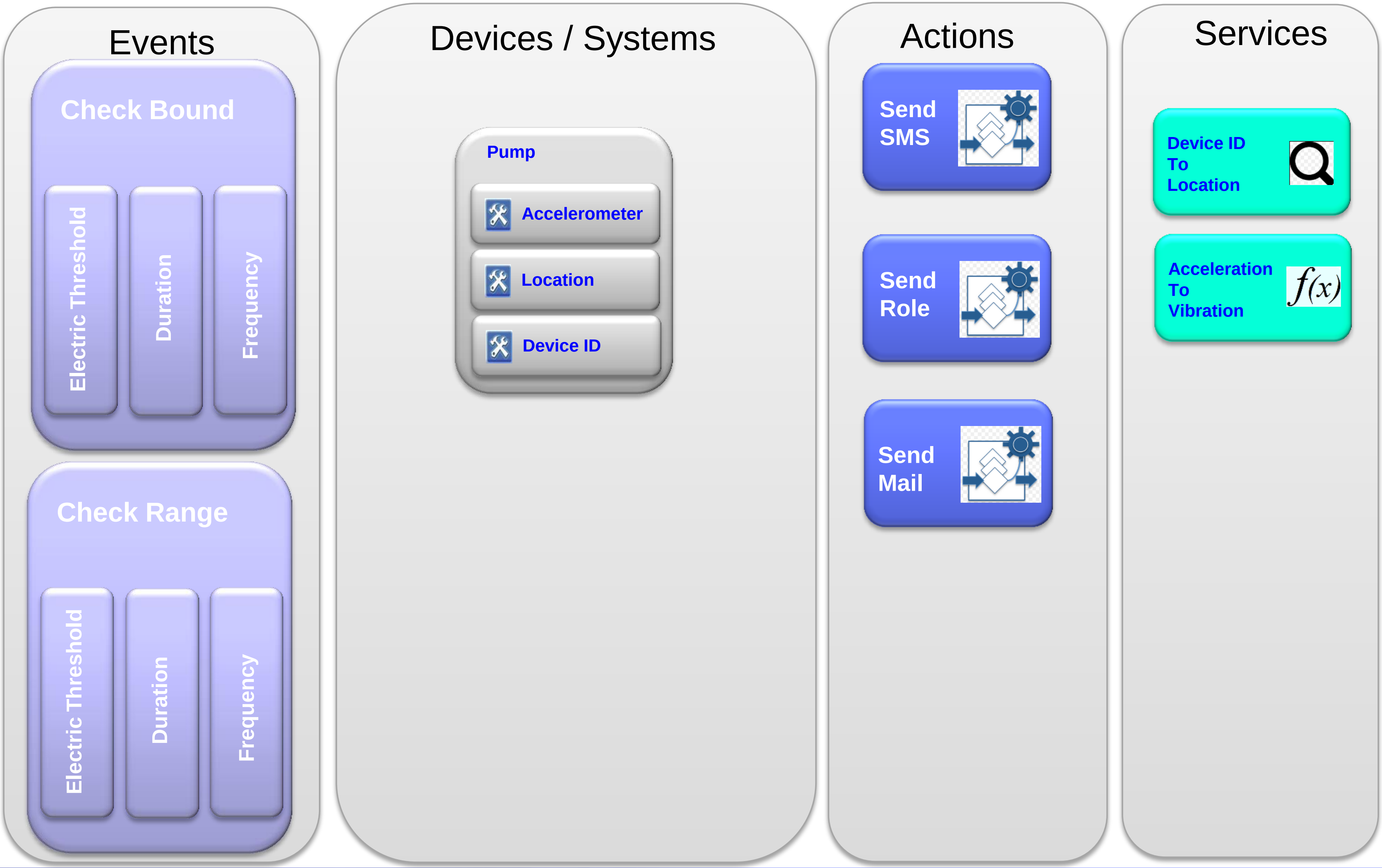
Fever Smart
- Temperature
- Device ID

TI SensorTag
- Accelerometer
- Temperature
- Device ID

Actions
- Send SMS
- Send Mail
- Vibrate

Services
- Employee To Manager
- Device ID To Person

Engineering Knowledge Base: IoT Catalog

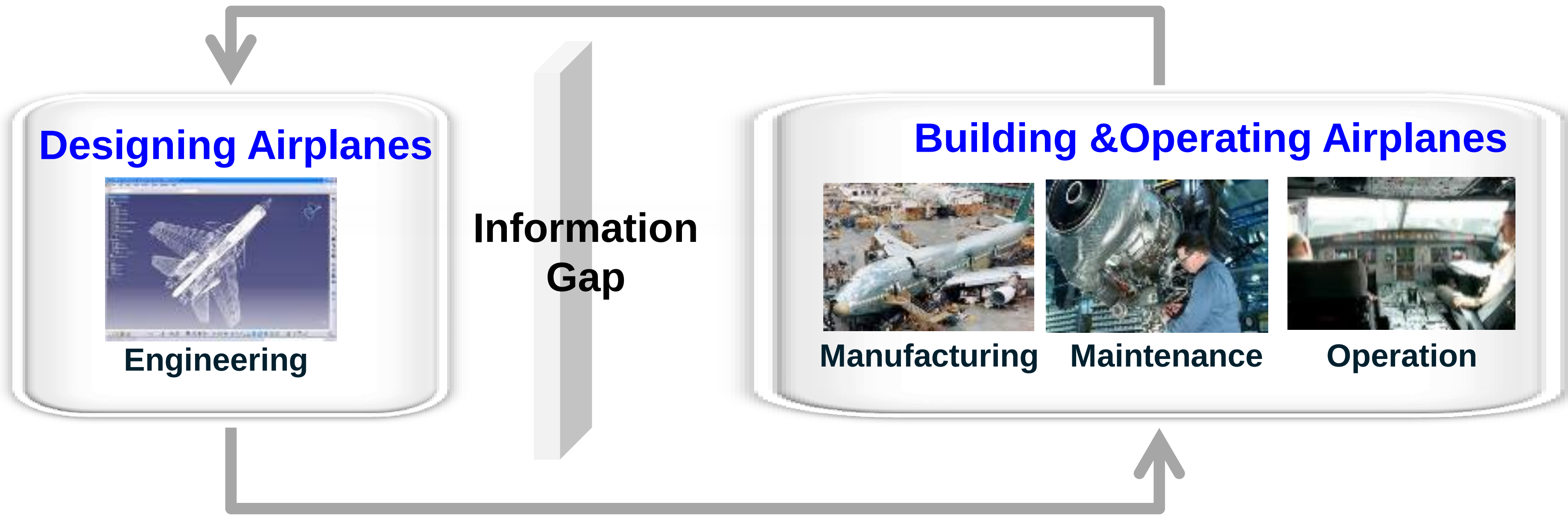


Agenda

- From SE to MBCE
- AOW background
- PORTALS
- **FAME**
- EMI
- DANSE
- Summary

FAME: Framework for Affordability Modeling & Evaluation

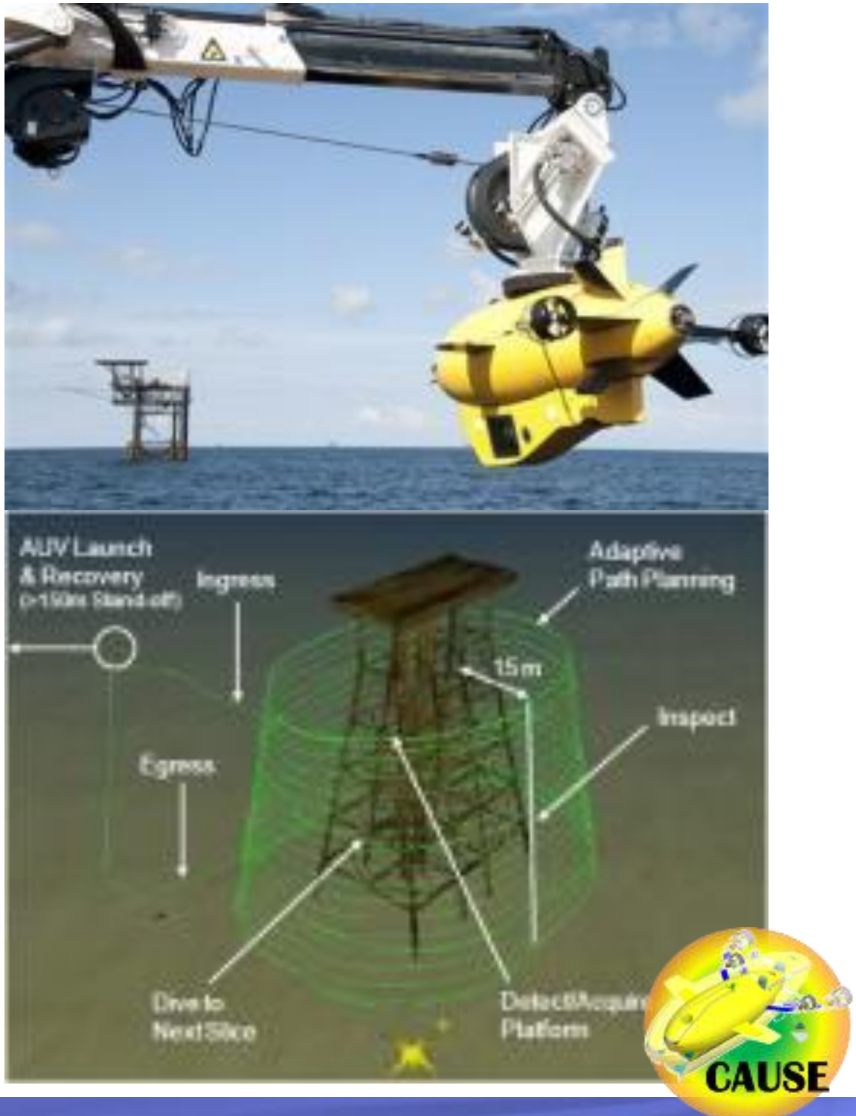
- Joint project with Lockheed Martin
- Currently: Tools exist for product optimization and operations optimization with no links in between
- Goal: Reduce operating costs by **optimizing the product** (and not the operations)



Solution:

- **Use design models to find optimal operation strategies (e.g. maintenance)**
- **Use design models for asset management tools customization**

FAME Use Case: Unmanned Underwater Vehicle



- Metrics
  - Production costs (up-front materials & fabrication)
  - Mission costs (vessel & crew for vehicle deployment & recovery)
  - Maintenance costs (planned upkeep & corrective repairs)
  - Availability (is the vehicle operational when it is needed)
- UUV designs are valuated using LM Palm Beach **CAUSE** analysis tool (**C**onceptual **A**utomated **U**UV **S**izing **E**nvironment)

Selection of Vehicle Architecture Directly Influences Cost and Availability Metrics

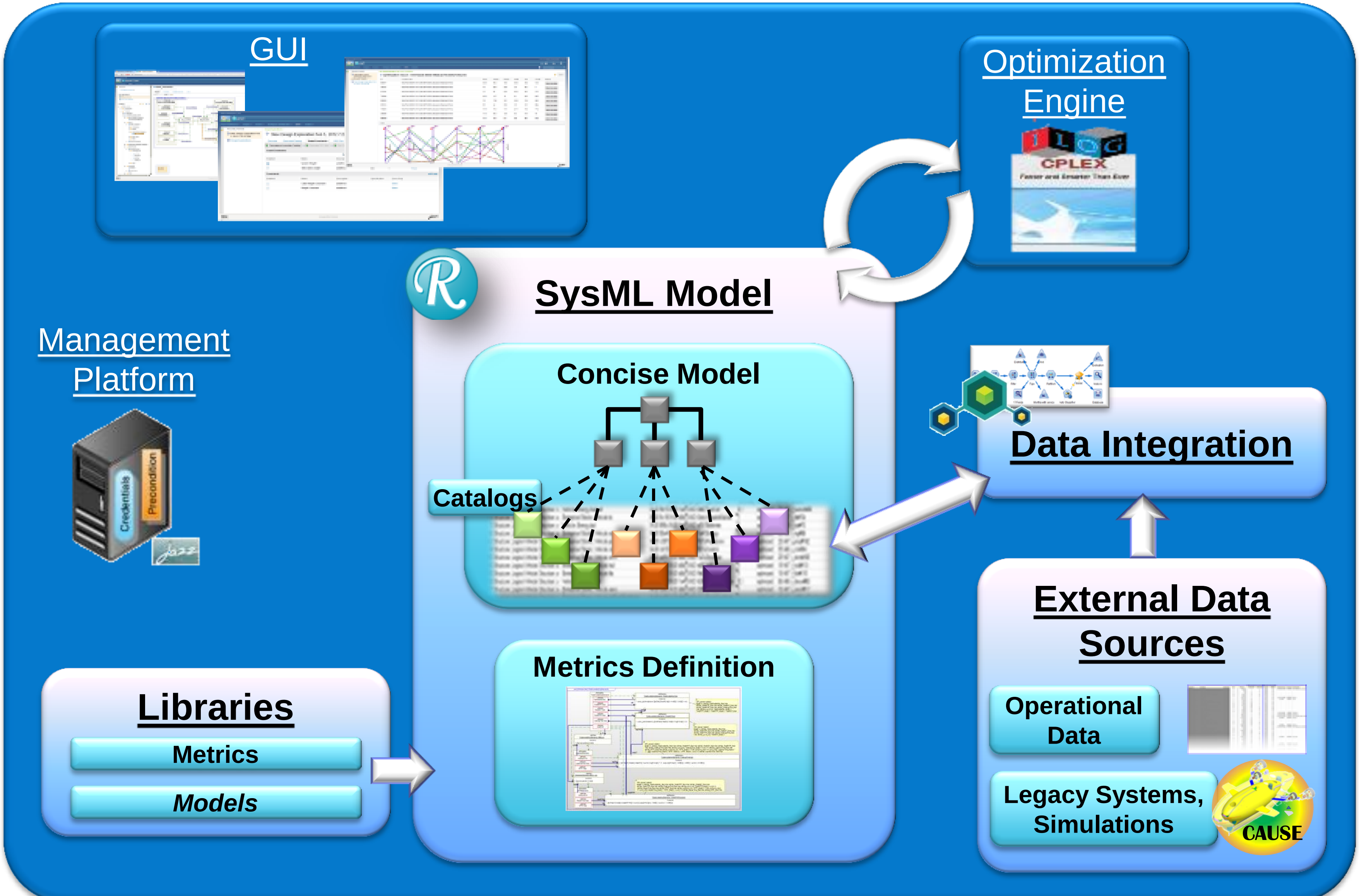
FAME New Capabilities

- Definition of libraries to capture reusable common metrics and processes
  - Key metrics: life cycle cost & system availability
- Expansion of user viewpoints feeding optimization
  - External legacy analysis models
    - Ability to protect IP of source models through “Black Box” integration
  - Existing operational data from procurement, fabrication, and operations & maintenance systems

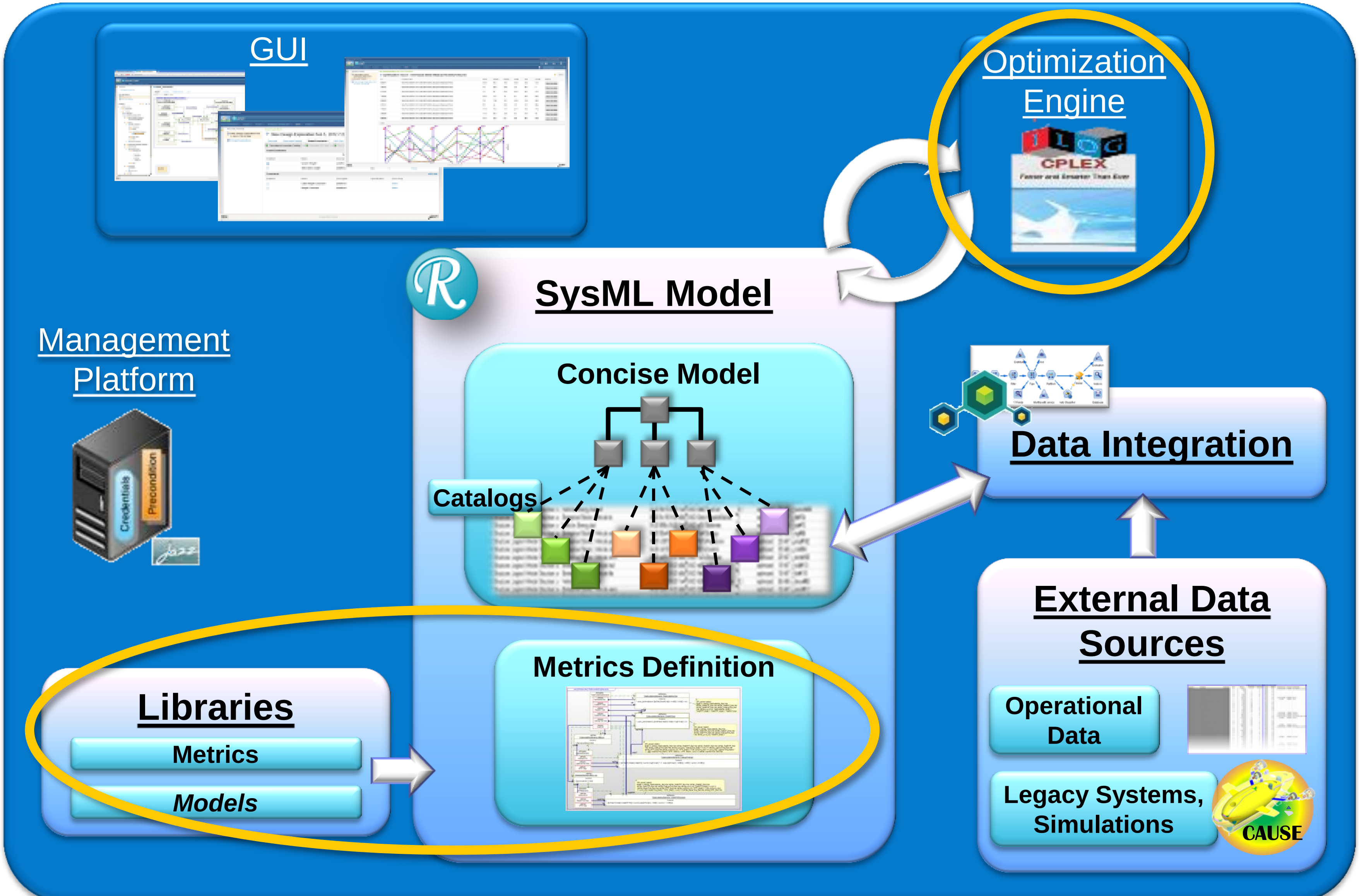
FAME Enhances Reuse and Usability Features of AOW

FAME

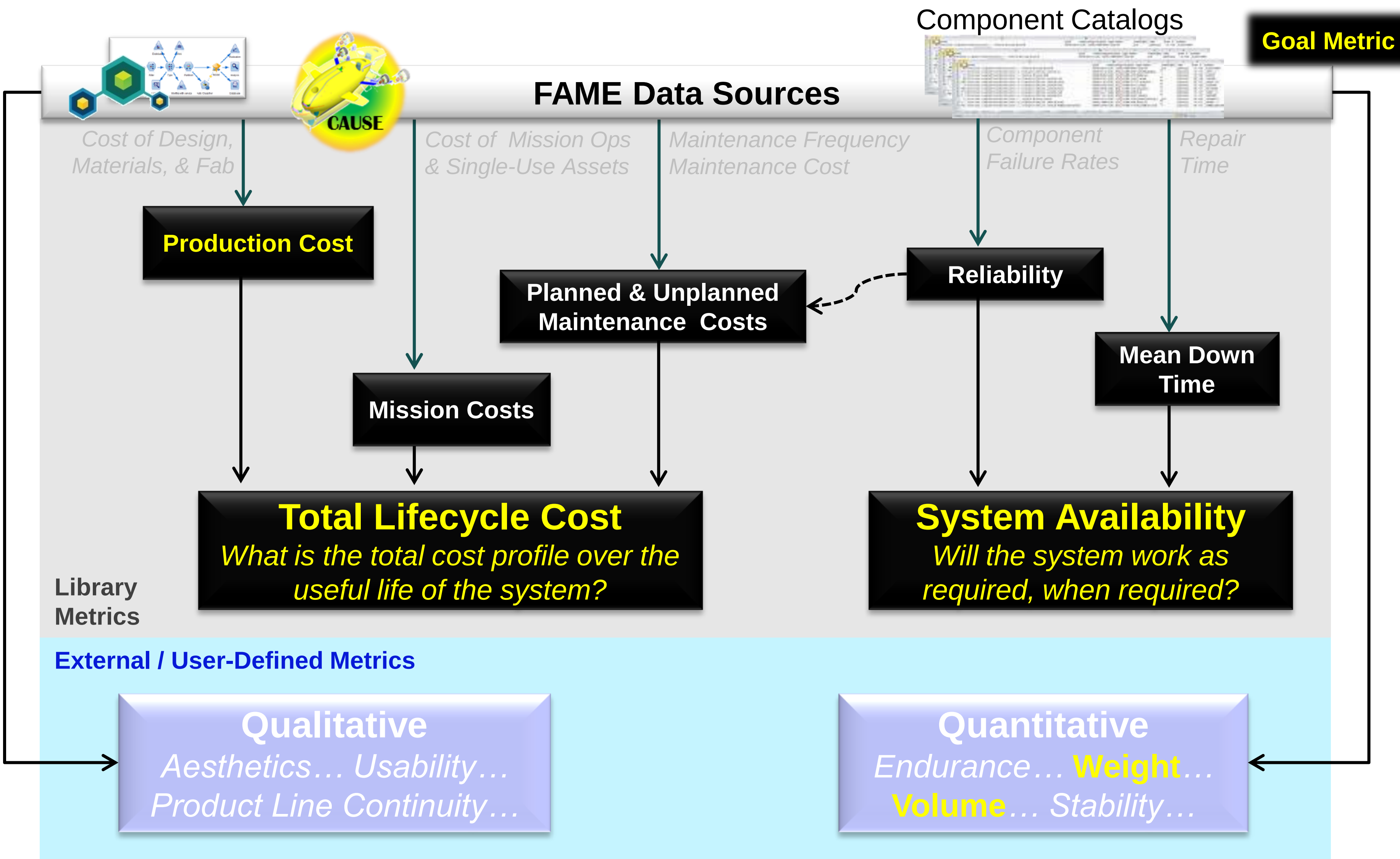
Framework for Affordability Modeling & Evaluation



FAME
Framework for Affordability Modeling & Evaluation



Metrics for Affordability



Balancing top level metrics = maximizing value to achieve affordability

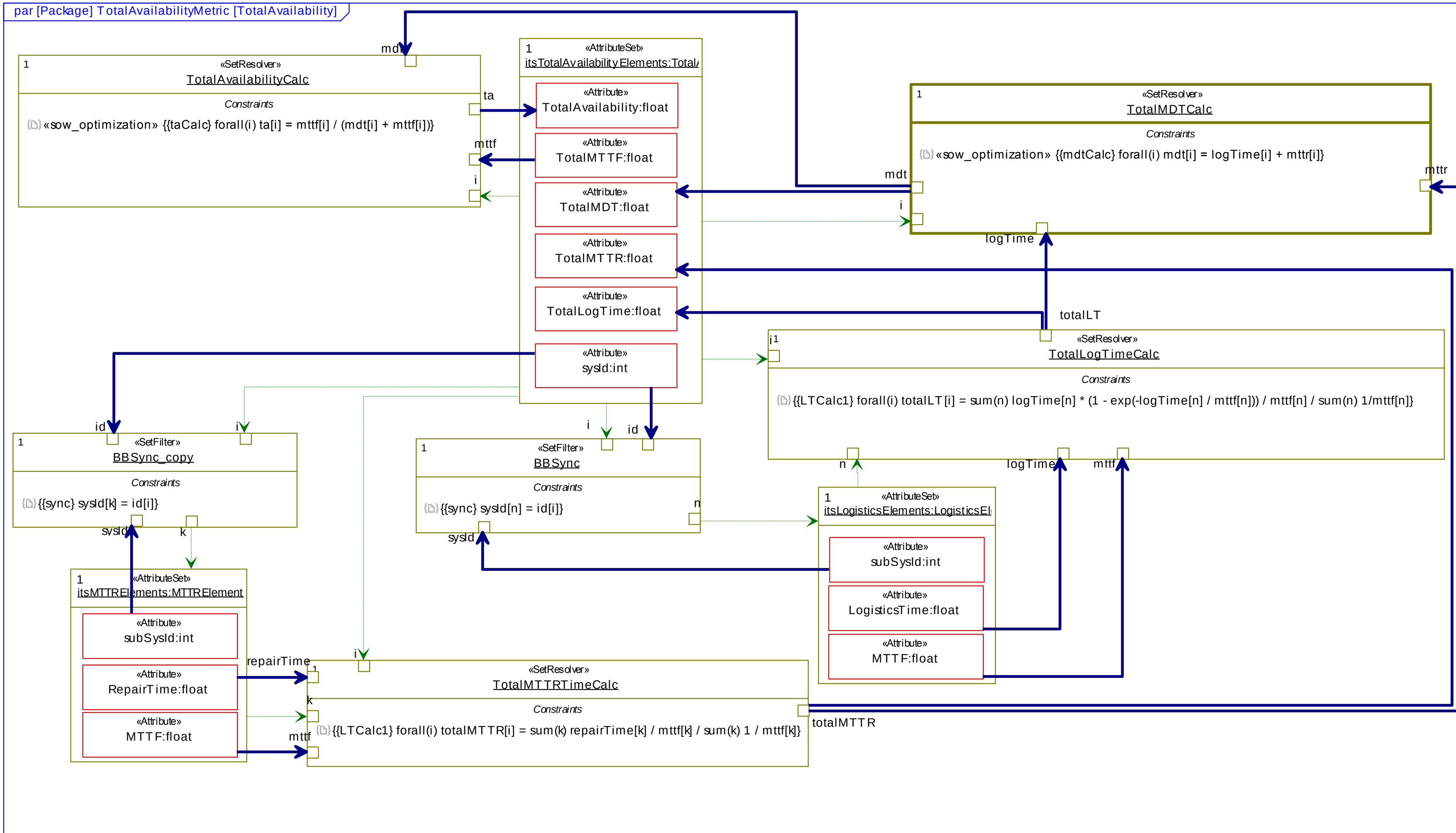
Metrics Library Concept

- SysML Parametric Diagram notation captures the attributes and formulas that define Goal Metrics for the optimization
- Blocks define sets of attributes required of architecture elements to support computing the given metrics
  - Block elements are classification-by-property attribute sets
  - Architecture elements can inherit attribute sets

Common Library Metrics Are Independent of a Particular Design or Domain Model

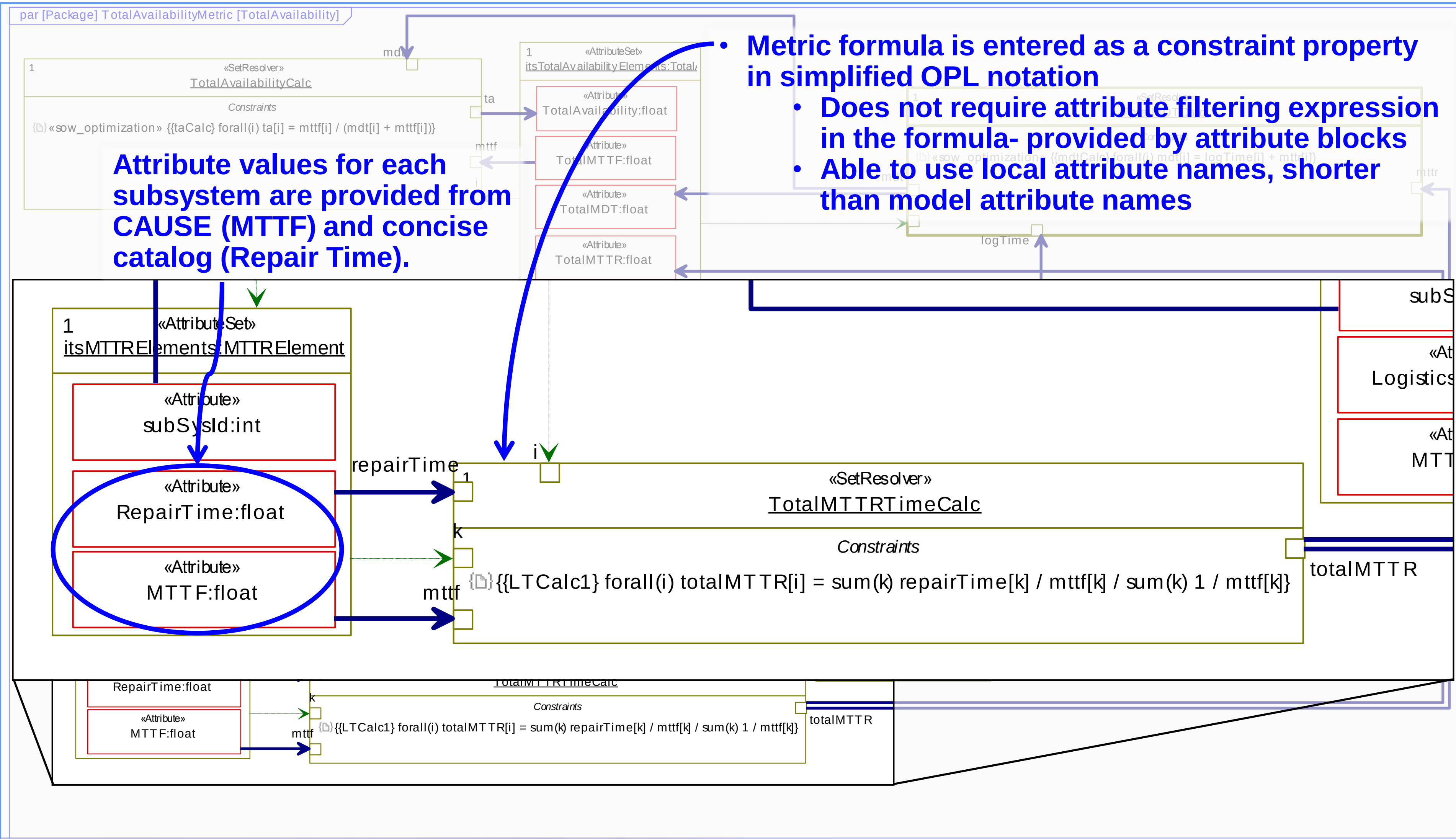
FAME Metrics Library

System Availability



FAME Metrics Library

System Availability

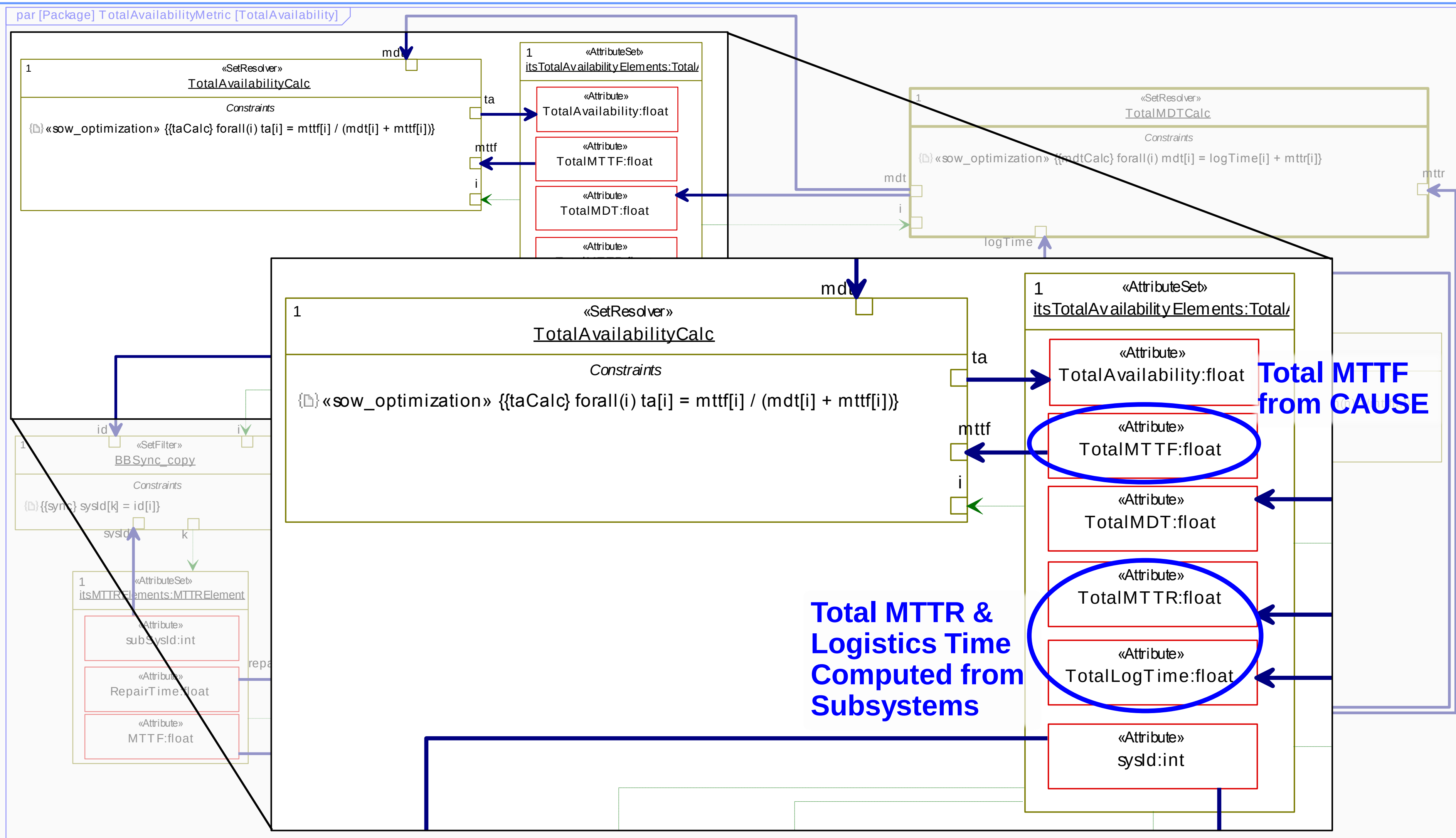


Attribute values for each subsystem are provided from CAUSE (MTTF) and concise catalog (Repair Time).

- Metric formula is entered as a constraint property in simplified OPL notation
  - Does not require attribute filtering expression in the formula- provided by attribute blocks
  - Able to use local attribute names, shorter than model attribute names

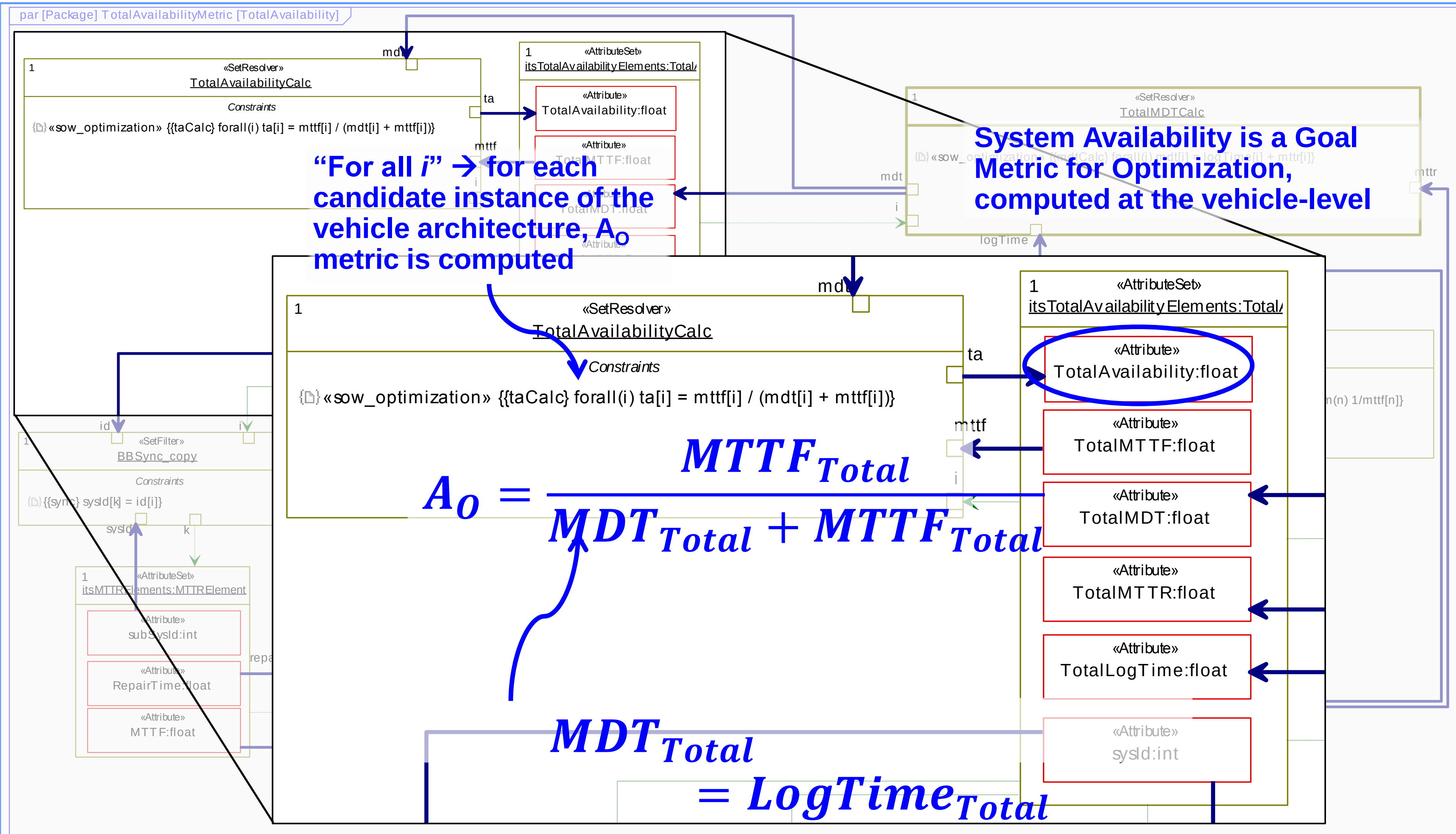
FAME Metrics Library

System Availability



FAME Metrics Library

System Availability



System Availability is a Goal Metric for Optimization, computed at the vehicle-level

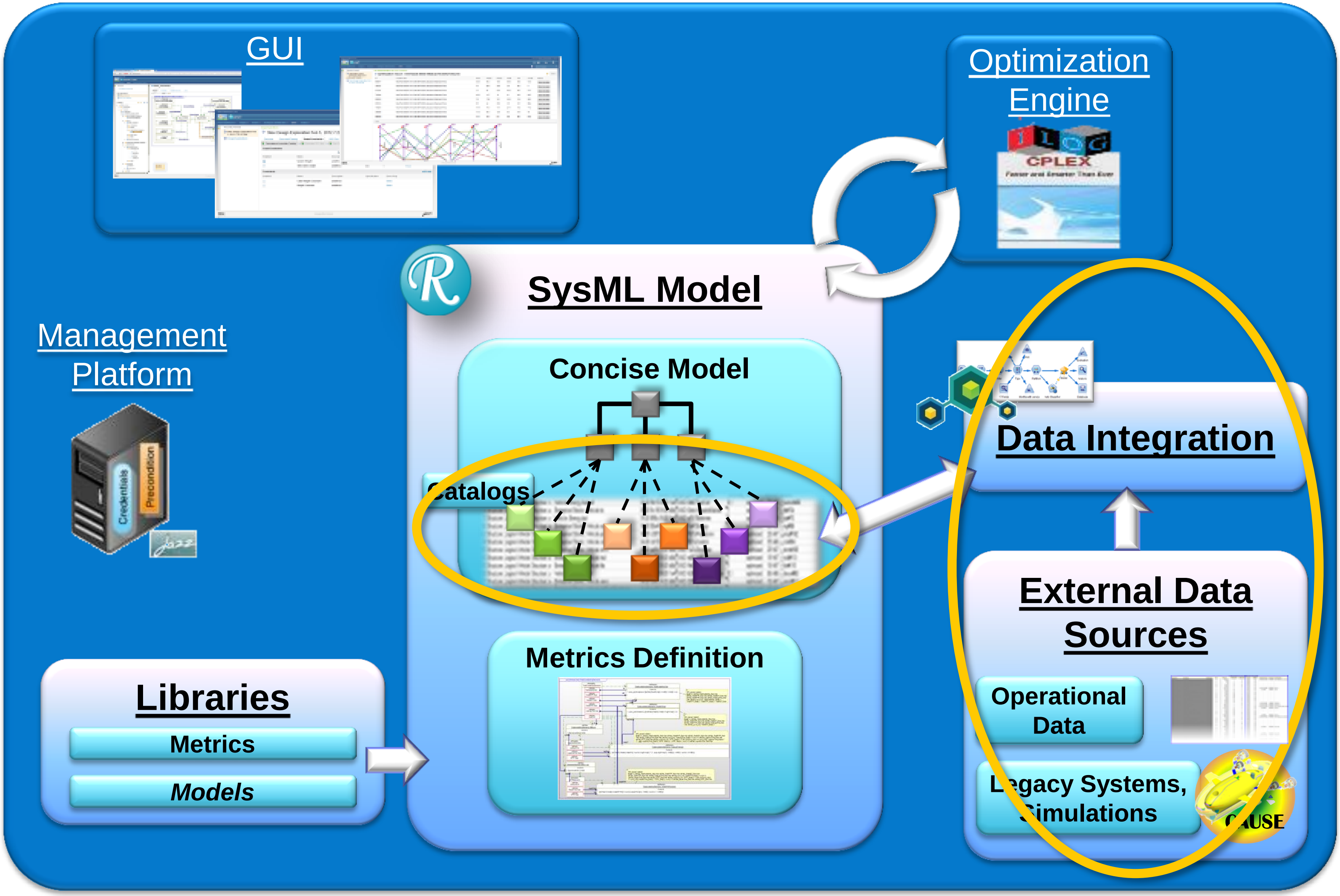
"For all *i*" → for each candidate instance of the vehicle architecture, A_O metric is computed

$$A_O = \frac{MTTF_{Total}}{MDT_{Total} + MTTF_{Total}}$$

$$MDT_{Total} = LogTime_{Total} + MTTR_{Total}$$

FAME

Framework for Affordability Modeling & Evaluation



Catalog Data

- Subsystem catalogs include key parameters differentiating physical options for each subsystem
  - Reliability Parameters
    - Maintenance Frequency
    - Maintenance Duration
    - Redundancy
  - Cost Parameters
    - Per-Mission Operations Cost

Energy Catalog

int	int	int	int	float	float	float
id	energy_type	IN_ENERGY_specificE	energy_fuel_cell_type	MissionCost	MaintenanceFreq	MaintenancePlanCost
3500000	1	68	1	0	18	600
3500000	1	39	1	0	18	1000
3500000	1	62	1	0	18	400
3500000	1	69	[illegible]	[illegible]	18	800
3500000	2	68	[illegible]	[illegible]	18	1200
3500000	2	68	[illegible]	[illegible]	[illegible]	[illegible]
3500000	2	68	[illegible]	[illegible]	[illegible]	[illegible]
3500000	2	68	[illegible]	[illegible]	[illegible]	[illegible]

Propulsion Catalog

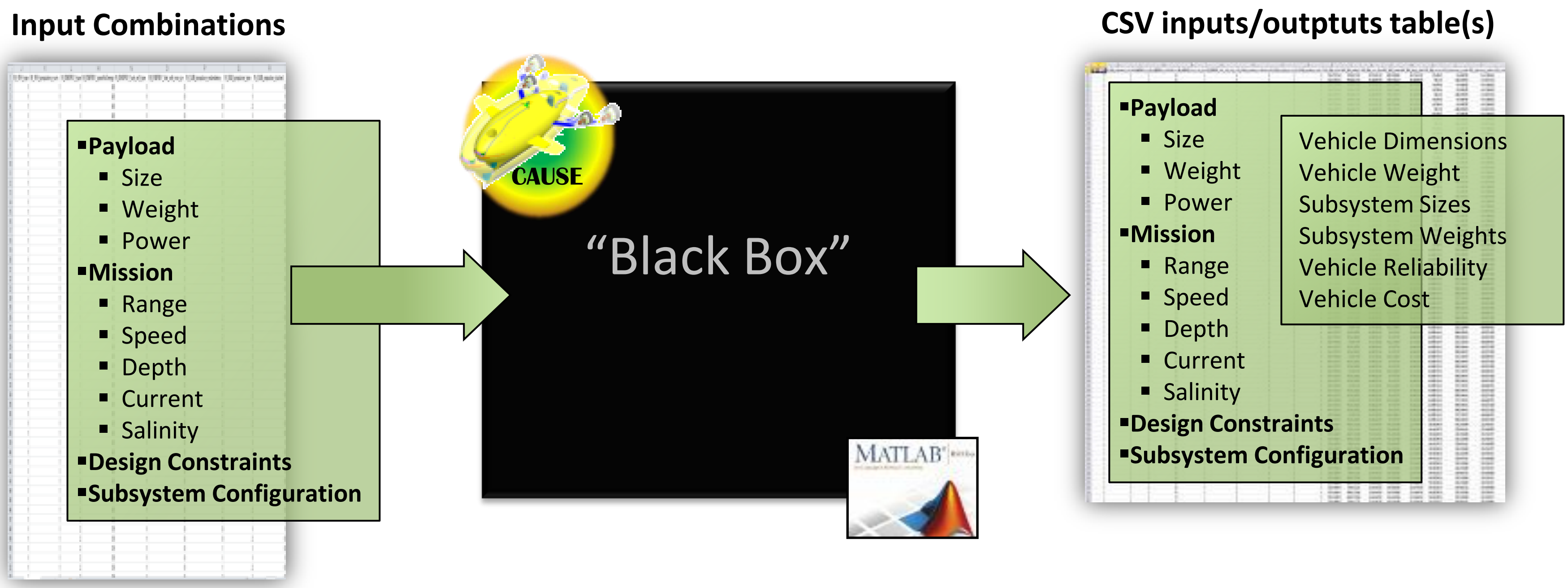
int	float	float	float	float	float
id	IN_SUB_propulsor_type	IN_SUB_propulsor_ducted	IN_VEH_propulsors_num	IN_SUB_propulsor_redundancy	MaintenanceFreq
13500000	1	0	1	0	35
13500001	1	1	1	0	35
13500002	2	1	1	0	35
13500003	1	0	2	0	35
13500004	1	1	2	0	35
13500005	2	1	2	0	35
13500006	1	0	2	1	35
13500007	1	1	2	1	35
13500008	2	1	2	1	35

FAME Users Define Cost & Performance Characteristics of Trade Options in Concise Catalog

NOTE: Numerical values are fictional, not actual, and intended only to demonstrate the functionality of FAME.

Integration of Legacy Analyses

- LM CAUSE is represented in FAME as a black box entity to protect IP
- Inputs & outputs are captured as an approximation model connected to the UUV Concise Model
- FAME can also integrate legacy analyses as white / gray box models

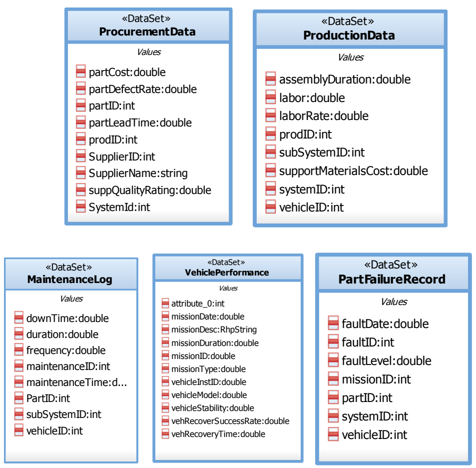


Black Box Integration Provides a Method to Protect Intellectual Property

Operational data integration

- Operational data provides the opportunity to enhance trade assessments with real measured cost and performance values for trade options
- Operational data is often in a format that does not readily support direct processing in trade metrics
- Challenge: how to integrate Operational Data with Data for Optimization?

Operational data



- **Large data set**
- **Different structure / sources/ formats**

How to fill the Manufacturing Labor Time attribute with measured Operational Data?

Catalog data

Energy

subSystemID	Cost	Labor Cost
1001	100	
1002	200	
1003	50	
1004	400	
1005	20	

Propulsion

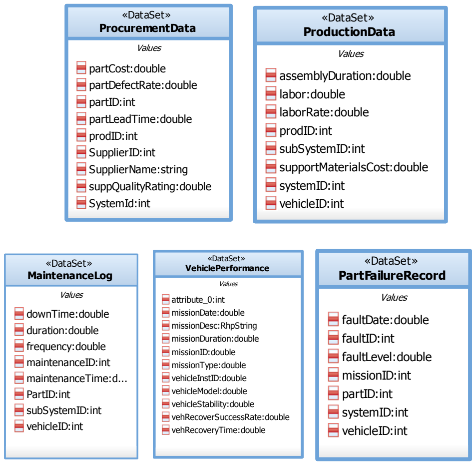
subSystemID	Cost	Labor Cost
2001	80	
2002	70	
2003	78	
2004	50	
2005	70	

- **Catalog data – small data set**
- **Input for the Optimization Engine**

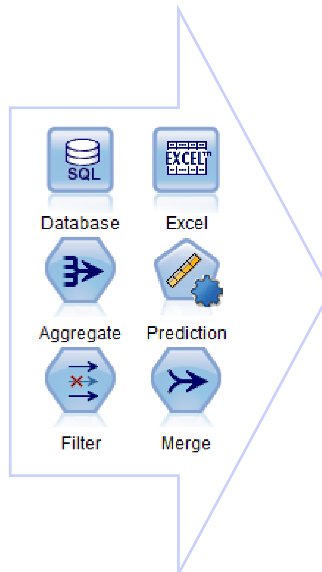
NOTE: Numerical values are fictional, not actual, and intended only to demonstrate the functionality of FAME.

Operational data integration

Operational data



- **Large data set**
- **Different structure / sources/ formats**



Catalog data

Energy

subSystemID	Cost	Labor Cost
1001	100	
1002	200	
1003	50	
1004	400	
1005	20	

Propulsion

subSystemID	Cost	Labor Cost
2001	80	
2002	70	
2003	78	
2004	50	
2005	70	

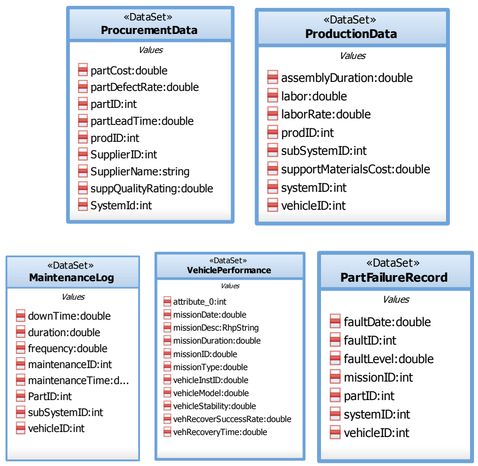
- **Catalog data – small data set**
- **Input for the Optimization Engine**

Use data flow definition & apply data transformation

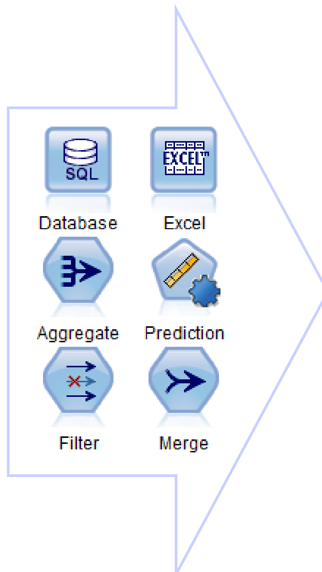
NOTE: Numerical values are fictional, not actual, and intended only to demonstrate the functionality of FAME.

Operational data integration

Operational data



- Large data set
- Different structure / sources/ formats



Catalog data

Energy

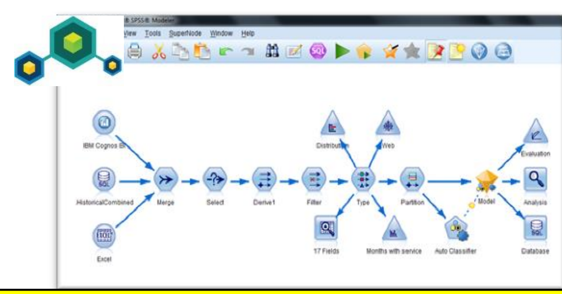
subSystemID	Cost	Labor Cost
1001	100	25
1002	200	30
1003	50	28
1004	400	17
1005	20	33

Propulsion

subSystemID	Cost	Labor Cost
2001	80	14
2002	70	15
2003	78	13.5
2004	50	17
2005	70	12

- Catalog data – small data set
- Input for the Optimization Engine

Solution: IBM SPSS Modeler



***NOTE: Numerical values are fictional, not actual, and intended only to demonstrate the functionality of FAME.**

Operational Data Integration

Catalog data for Propulsion

The Catalog ID

IDs to correlate with Cause data

id	IN_SUB_propulso	IN_SUB_propulsor_ductec	IN_SUB_propulsor_redu	IN_SUB_propulsor_t	MaintenanceFr	MaintenancePlanCo	MaintenanceUnPlanCo	LogisticsTime	NumOfSpares	RepairTime	name
16100000	1	1	0	1	35	4000	6000	6000	1	24	Single_Duct_NoRed
16100001	1	0	1	2	35	6000	6000	4000	2	18	Double_Open_Redun

CAUSE data for Propulsion

The CAUSE data ID

Input configuration

CAUSE output

Extract from the Manufacturing Operational Data

id	IN_SUB_propulsor_num	IN_SUB_propulsor_redundancy	IN_SUB_propulsor_type	IN_SUB_propulsor_ducted	OUT_propulsor_volume	OUT_Propulsor_Diameter	ConfigId	MC_mttf_effective	LaborTime	UnitCost
38000000	1	0	1	1	46623.73928	1.854019446	1	1414788.576		
38000001	1	0	1	1	25056.1019	1.507277846	2	1414788.576		
38000002	1	0	1	1	29362.26699	1.58912605	3	1414788.576		
38000003	2	1	1	0	30295.79777	2.538524122	4	1414788.576		
38000004	2	1	1	0	15009.18252	2.008299673	5	1414788.576		
38000005	2	1	1	0	17916.54636	2.130503092	6	1414788.576		
38000006	1	0	1	1	40343.11383	1.766702423	7	1414788.576		

Manufacturing data

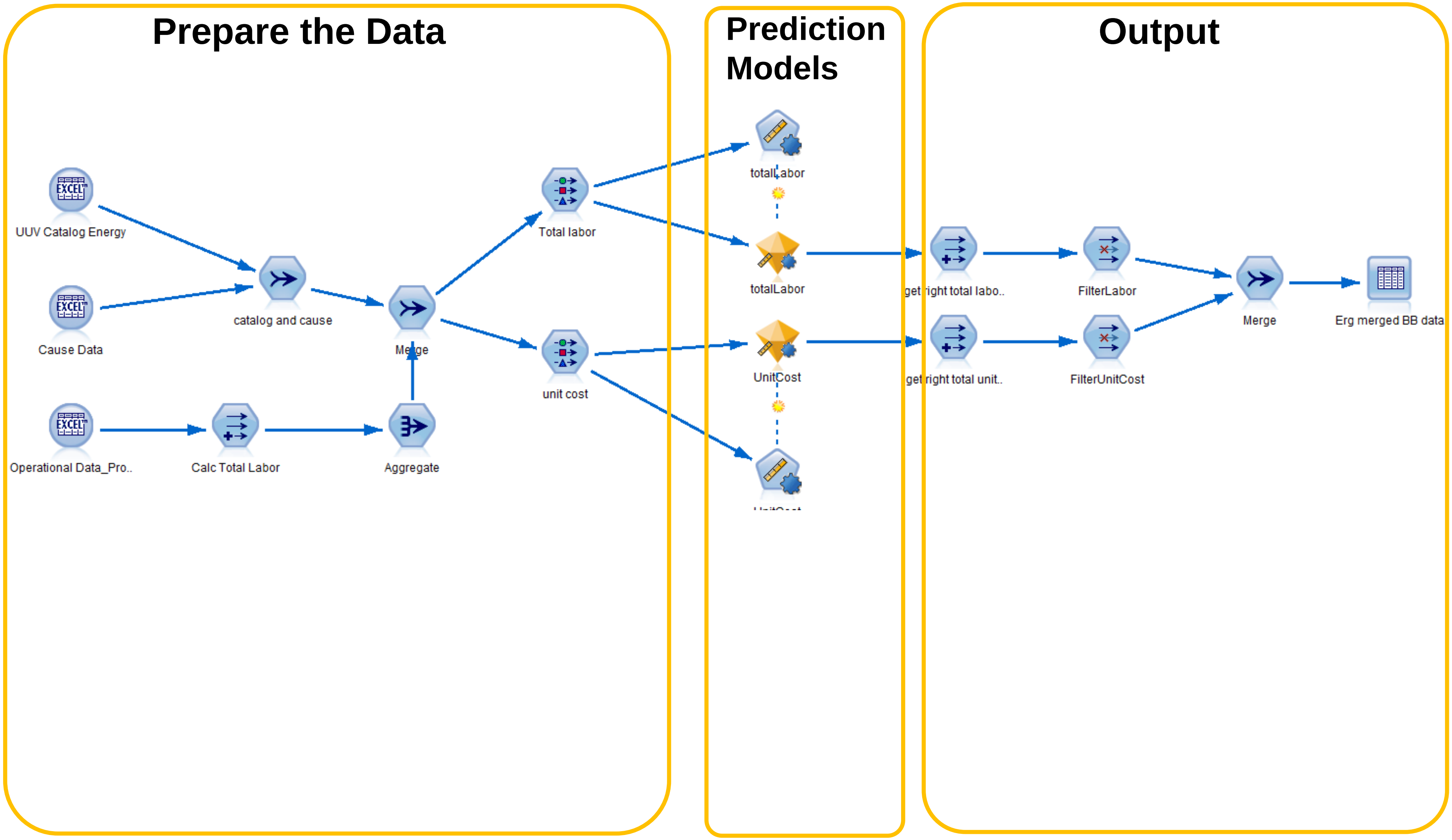
UUV production data modeled after SAP schema

Additional data input supports mapping operational data to

Program ID	Part Name	PartNumber	Qty	UnitCost	Manufacturing Labor (hrs)	Procurement Labor (hrs)	RefVehVol (in^3)	RefVehkWh (kWhr)	Catalog Element	Catalog ID	Catalog Name

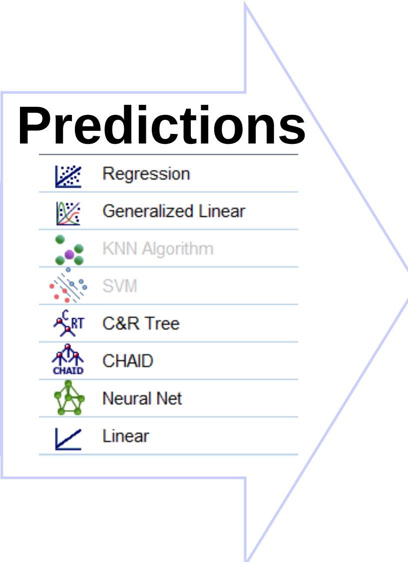
NOTE: Numerical values are fictional, not actual, and intended only to demonstrate the functionality of FAME.

The SPSS Process for Energy



SPSS Results for Energy

ConfigId	id	name	UnitCost	totalLabor
1.000	4800000....	Engy Batt Secondary	121439....	21.818
16.000	4800000....	Engy Batt Secondary	121439....	21.818
34.000	4800000....	Engy Batt Secondary	121439....	21.818
13.000	4800000....	Engy Batt Secondary	121439....	21.818
4.000	4800000....	Engy Batt Secondary	121439....	21.818
31.000	4800000....	Engy Batt Secondary	121439....	21.818
22.000	4800000....	Engy Batt Secondary	121439....	21.818
7.000	4800000....	Engy Batt Secondary	121439....	21.818
28.000	4800000....	Engy Batt Secondary	121439....	21.818
19.000	4800000....	Engy Batt Secondary	121439....	21.818
10.000	4800000....	Engy Batt Secondary	121439....	21.818
25.000	4800000....	Engy Batt Secondary	121439....	21.818
18.000	4800002....	Engy Batt FutureSec	$null$	$null$
33.000	4800002....	Engy Batt FutureSec	$null$	$null$
30.000	4800002....	Engy Batt FutureSec	$null$	$null$
27.000	4800002....	Engy Batt FutureSec	$null$	$null$
24.000	4800002....	Engy Batt FutureSec	$null$	$null$
21.000	4800002....	Engy Batt FutureSec	$null$	$null$
36.000	4800002....	Engy Batt FutureSec	$null$	$null$
15.000	4800002....	Engy Batt FutureSec	$null$	$null$
12.000	4800002....	Engy Batt FutureSec	$null$	$null$
9.000	4800002....	Engy Batt FutureSec	$null$	$null$
6.000	4800002....	Engy Batt FutureSec	$null$	$null$
3.000	4800002....	Engy Batt FutureSec	$null$	$null$
35.000	4800001....	Engy Batt Primary	337237....	23.000
11.000	4800001....	Engy Batt Primary	337237....	23.000
26.000	4800001....	Engy Batt Primary	337237....	23.000
17.000	4800001....	Engy Batt Primary	337237....	23.000
8.000	4800001....	Engy Batt Primary	337237....	23.000
29.000	4800001....	Engy Batt Primary	337237....	23.000
14.000	4800001....	Engy Batt Primary	337237....	23.000
5.000	4800001....	Engy Batt Primary	337237....	23.000
32.000	4800001....	Engy Batt Primary	337237....	23.000
23.000	4800001....	Engy Batt Primary	337237....	23.000
2.000	4800001....	Engy Batt Primary	337237....	23.000
20.000	4800001....	Engy Batt Primary	337237....	23.000



ConfigId	id	name	totalLabor	UnitCost
1.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
16.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
34.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
13.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
4.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
31.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
22.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
7.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
28.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
19.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
10.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
25.000	4800000.0...	Engy Batt Secondary	21.818	121439.636
18.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
33.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
30.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
27.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
24.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
21.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
36.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
15.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
12.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
9.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
6.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
3.000	4800002.0...	Engy Batt FutureSec	21.818	121439.636
35.000	4800001.0...	Engy Batt Primary	23.000	337237.500
11.000	4800001.0...	Engy Batt Primary	23.000	337237.500
26.000	4800001.0...	Engy Batt Primary	23.000	337237.500
17.000	4800001.0...	Engy Batt Primary	23.000	337237.500
8.000	4800001.0...	Engy Batt Primary	23.000	337237.500
29.000	4800001.0...	Engy Batt Primary	23.000	337237.500
14.000	4800001.0...	Engy Batt Primary	23.000	337237.500
5.000	4800001.0...	Engy Batt Primary	23.000	337237.500
32.000	4800001.0...	Engy Batt Primary	23.000	337237.500
23.000	4800001.0...	Engy Batt Primary	23.000	337237.500
2.000	4800001.0...	Engy Batt Primary	23.000	337237.500
20.000	4800001.0...	Engy Batt Primary	23.000	337237.500

CAUSE does not have cost prediction for Future Battery

SPSS prediction capability evaluates Future Battery Unit Cost

NOTE: Numerical values are fictional, not actual, and intended only to demonstrate the functionality of FAME.

Agenda

- From SE to MBCE
- AOW background
- PORTALS
- FAME
- **EMI**
- DANSE
- Summary

EMI: Engineering Management Integrator

- SE cycle vs Project Management Gantt
- Cooperation instead of twisting arms
- IBM Research – Technion collaboration (Prof. Avy Shtub, Michal Iluz)
- Integration of AOW with Project Team Builder (PTB)

Time Management for Architecture Optimization

- Multi-mode Resource Constrained Project Scheduling Problem (MRCPSP)
  - project activities have several operational modes
  - each mode has its own duration and required set of resources
  - precedence constraints between activities
  - resources have a final capacity
  - solution defines the mode in which each activity is executed and schedules the activities

- Adjusting MRCPSP to AO
  - Synchronization of mode selection with architectural decisions
  - Part time job intensity
  - Variable period lengths
  - …

Mathematical formulation - model

AO-MRCPSP

Minimize $\{C_{max}, D\}$ (1)

Subject to

$$\sum_{j \in M_i} x_{ij} = 1 \qquad \forall\, i \in A \tag{2}$$

$$y_{jt} \leq x_{ij} \qquad \forall\, i \in A, j \in M_i, t \in P \tag{3}$$

$$w \cdot \tilde{y}_{it} \leq \sum_{j \in M_i} y_{jt} \qquad \forall\, i \in A, t \in P \tag{4}$$

$$\tilde{y}_{it} \geq \sum_{j \in M_i} y_{jt} \qquad \forall\, i \in A, t \in P \tag{5}$$

$$s_{it} \leq s_{i,t+1} \qquad \forall\, i \in A, t \in P | t < T \tag{6}$$

$$f_{it} \leq f_{i,t+1} \qquad \forall\, i \in A, t \in P | t < T \tag{7}$$

$$s_{it} \geq \tilde{y}_{it} \qquad \forall\, i \in A, t \in P \tag{8}$$

$$f_{it} \leq 1 - \tilde{y}_{it} \qquad \forall\, i \in A, t \in P \tag{9}$$

$$\tilde{y}_{it} \leq f_{i't} \qquad \forall\, i \in A, i' \in IP_i, t \in P \tag{10}$$

$$\sum_{j \in M_i} \sum_{t \in P} y_{jt} p_t \geq \sum_{j \in M_i} x_{ij} d_j \qquad \forall\, i \in A \tag{11}$$

$$\sum_{t \in P} (s_{it} - f_{it}) p_t \leq e \sum_{j \in M_i} x_{ij} d_j \qquad \forall\, i \in A \tag{12}$$

$$C_i = T_{max} - \sum_{t \in P} f_t p_t \qquad \forall\, i \in A \tag{13}$$

$$C_{max} \geq C_i \qquad \forall\, i \in A \tag{14}$$

$$u_{kt} = \frac{1}{v_k} \sum_{i \in A} \sum_{j \in M_i} y_{jt} r_{jk} \qquad \forall\, k \in R, t \in P \tag{15}$$

$$u_{kt} \leq 1 \qquad \forall\, k \in R, t \in P \tag{16}$$

$$u_k = \frac{\sum_{t \in P} u_{kt} p_t}{\sum_{t \in P} p_t} \tag{17}$$

$$B = \sum_{k \in R} u_k v_k b_k \tag{18}$$

$$A = \sum_{i \in A} \sum_{j \in M_i} x_{ij} a_j \tag{19}$$

$$D = A + B \tag{20}$$

$$\sum_{j \in M_i} x_{ij} n_j = q_{h_i} \qquad \forall\, i \in A \tag{21}$$

$$x_{ij}, \tilde{y}_{it}, s_{it}, f_{it} \in \{0,1\} \qquad 0 \leq y_{jt}, u_{kt}, u_k \leq 1 \qquad C_i, C_{max}, A, B, D \geq 0 \tag{22}$$

Mathematical formulation - AOW

$$\text{Minimize } \textit{Original objectives, Objectives } (1) \qquad (23)$$

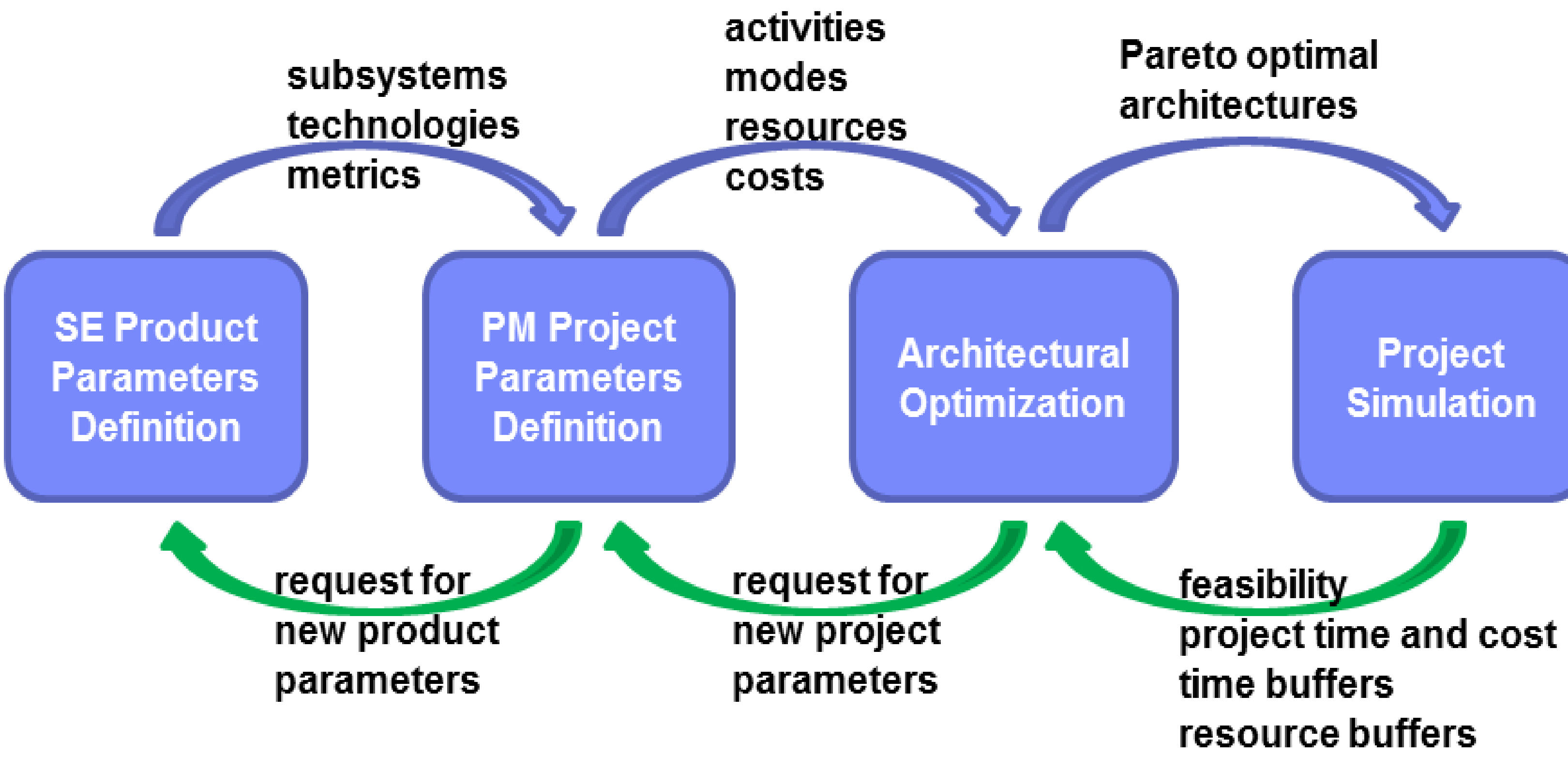
$$\text{Subject to}$$

$$\textit{Original architectural constraints} \qquad (24)$$

$$\text{Constraints } (2) - (22)$$

$$\textit{Subsystem/component type synchronization constraints} \qquad (25)$$

EMI Process



subsystems
technologies
metrics
activities
modes
resources
costs
Pareto optimal
architectures
SE Product Parameters Definition
PM Project Parameters Definition
Architectural Optimization
Project Simulation
request for
new product
parameters
request for
new project
parameters
feasibility
project time and cost
time buffers
resource buffers

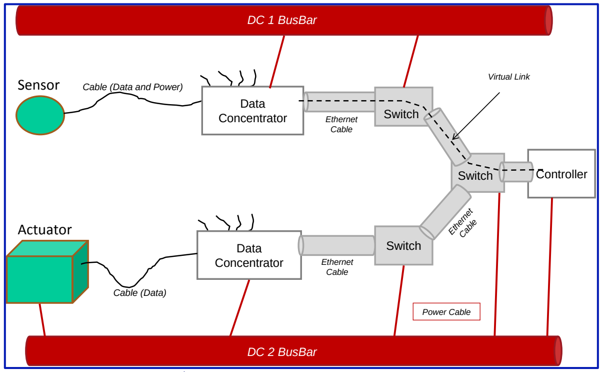
Airbus Group, Doors Management System

Development and Analysis of a Simplified Doors Control System

- **Monitor and Control Passenger Doors, Emergency Exits, and Cargo Doors**
- **Design a system out of existing components for best weight, cost, power etc.**

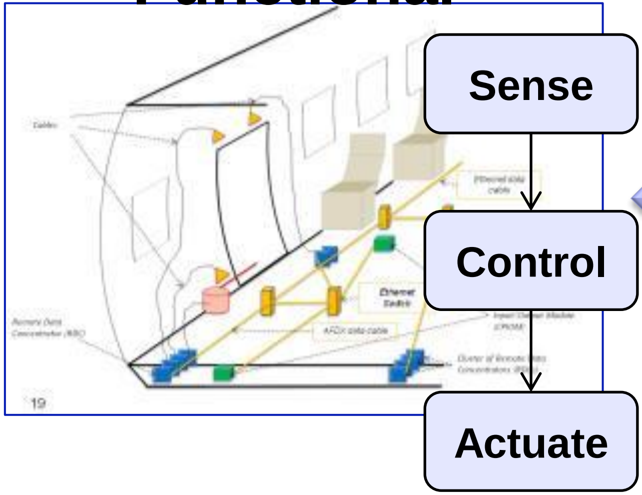
Development and Analysis of a Doors and Slides Control System

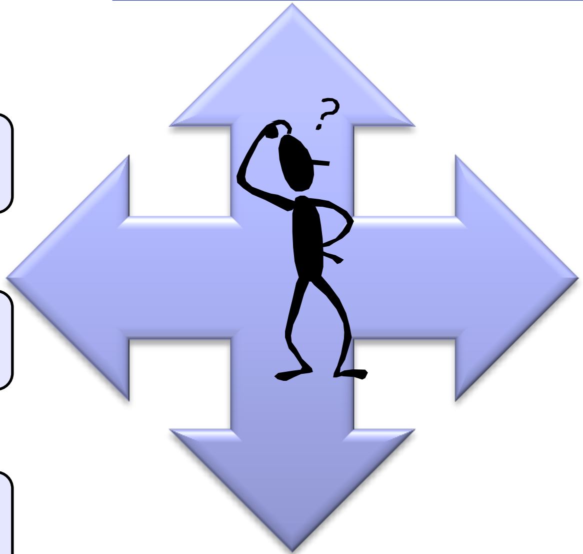
•Passenger Doors, Emergency Exits, and Cargo Doors



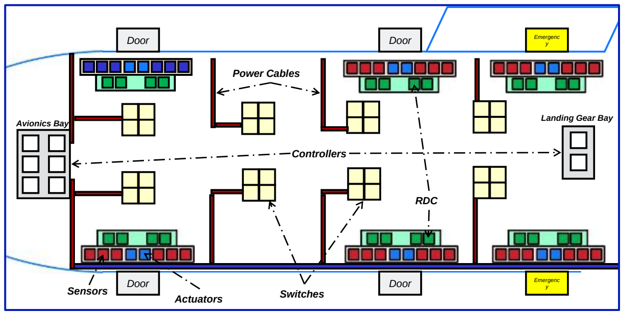
Structure

Functional





Geometrical

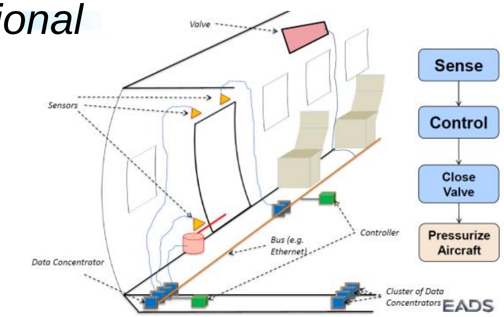


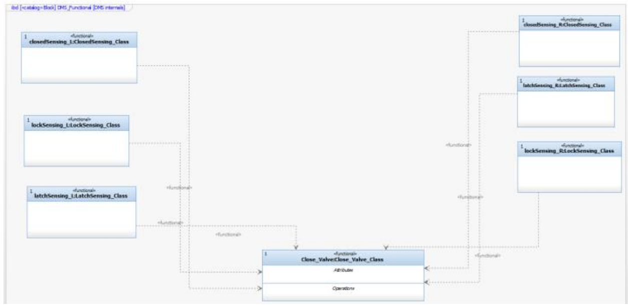
Design metrics

Weight, Cable length, Power distribution, Mapping, Allocation, Reliability …

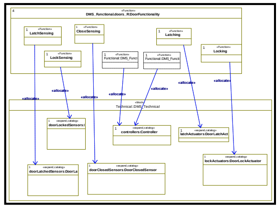
DMS: From user story to model

Functional

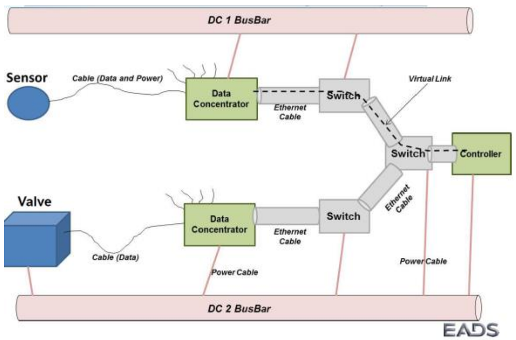


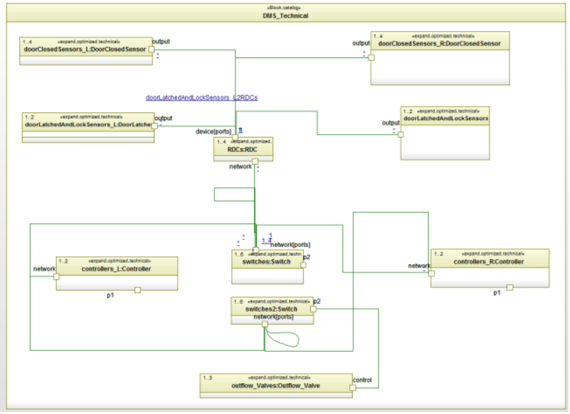


Mapping

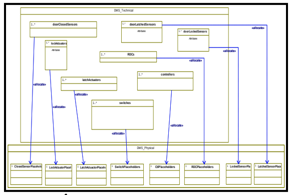


Technical

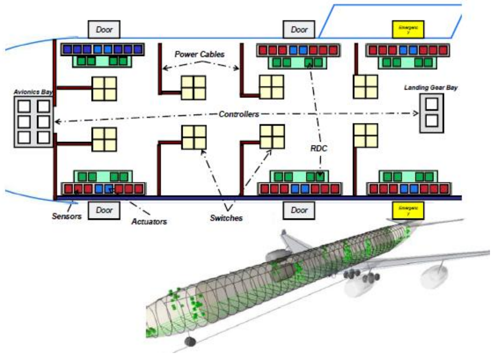


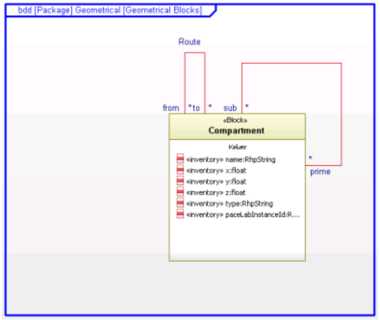


Allocation

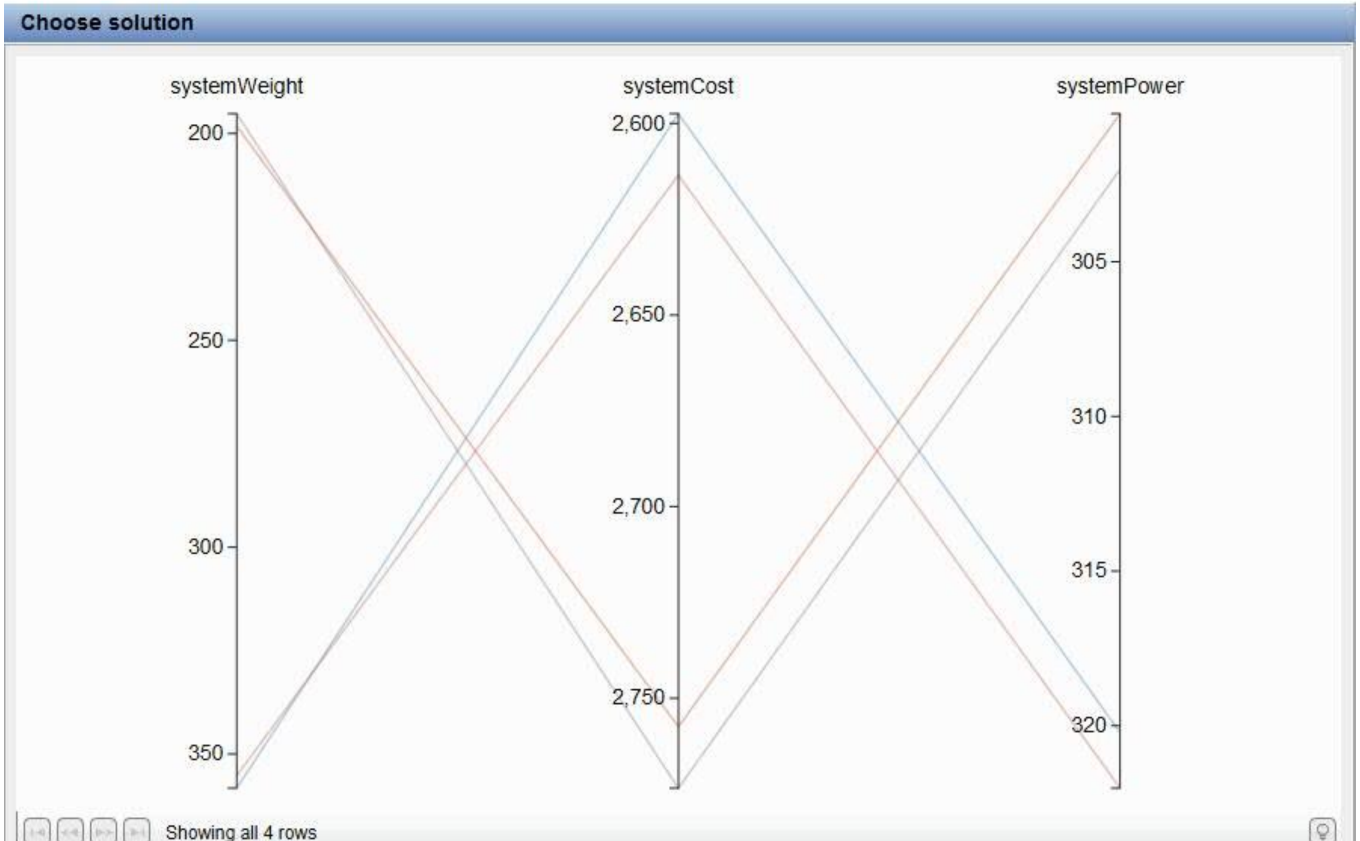


Geometrical





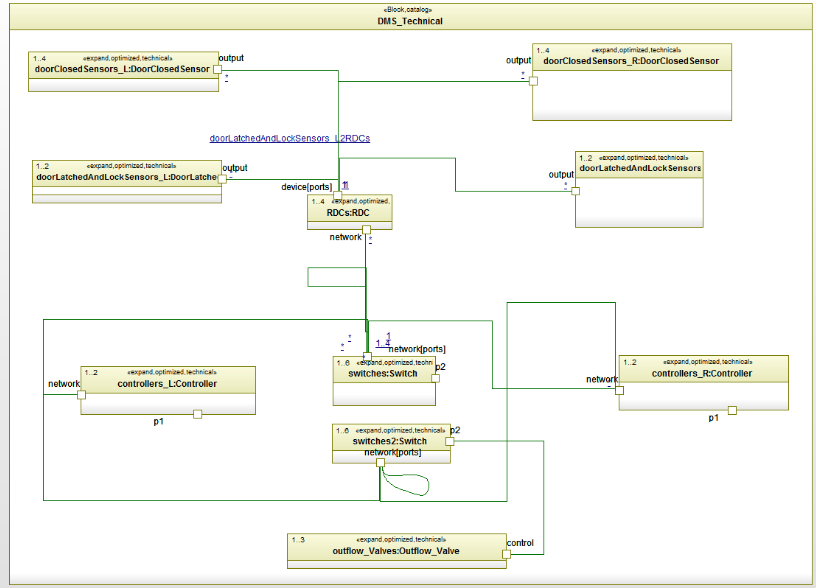
AOW – AO



iterationId	systemWeight	systemCost	systemPower
1	358.26	2597.5	320.22
2	195.26	2773.5	302.02
3	355.26	2613.5	322.02
4	198.26	2757.5	300.22

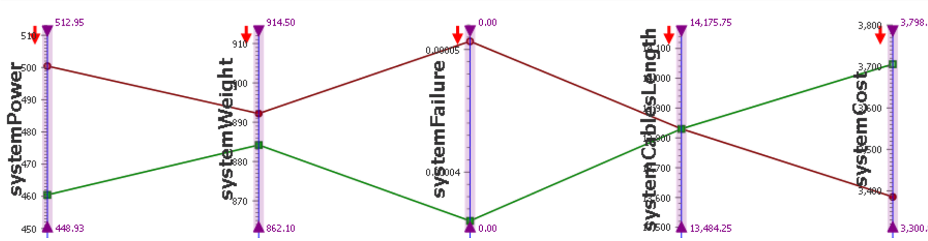
DMS: Results [1/2]

1. SysML modeling

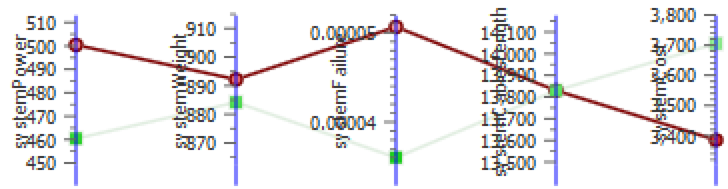


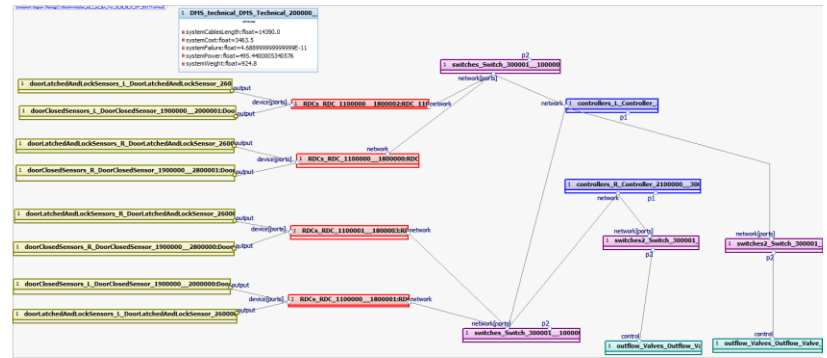
2. Run Optimization and show alternatives

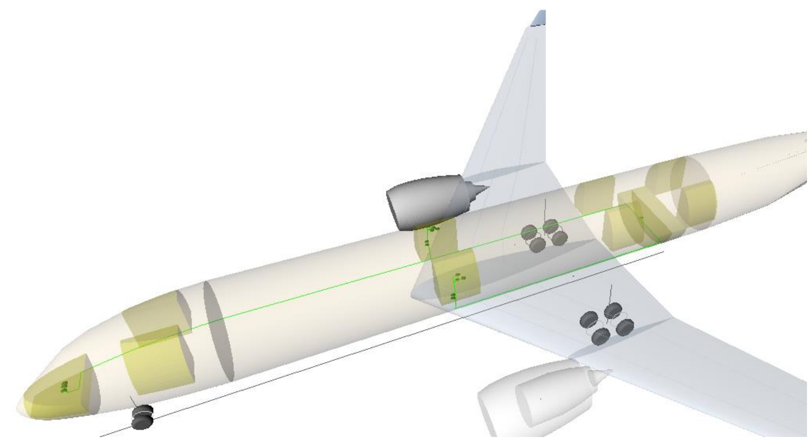
ID	systemPower	systemWeight	systemFailure	systemCablesLength	systemCost	Finished at	Duration
2ece937c-a4b9-4ac8-b0ab-702de3a1c94a	500.44	892.20	5.066E-5	13830.00	3385.50	May 23, 2013 11:14:54 AM	942 sec
3232cbf2-0383-4500-811a-52d643079cd3	460.44	884.20	3.602E-5	13830.00	3705.50	May 23, 2013 11:10:54 AM	938 sec



3. Visualize the alternatives

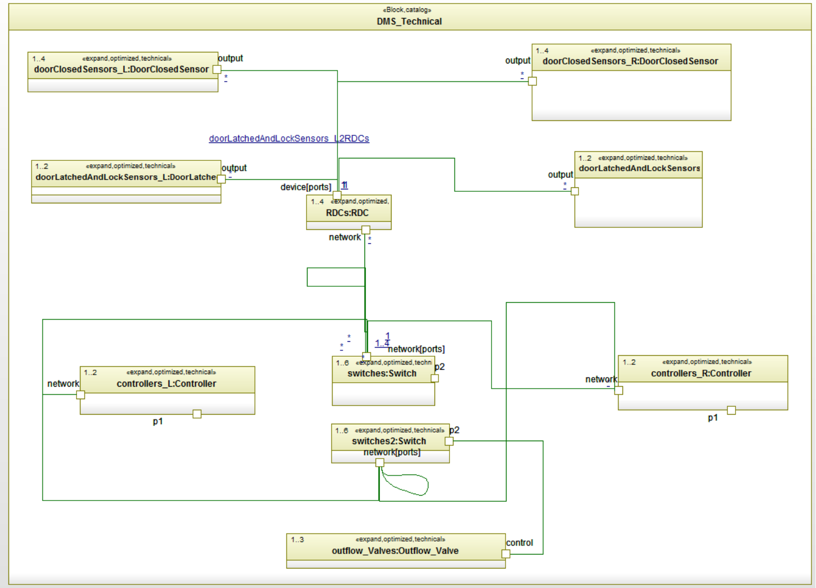






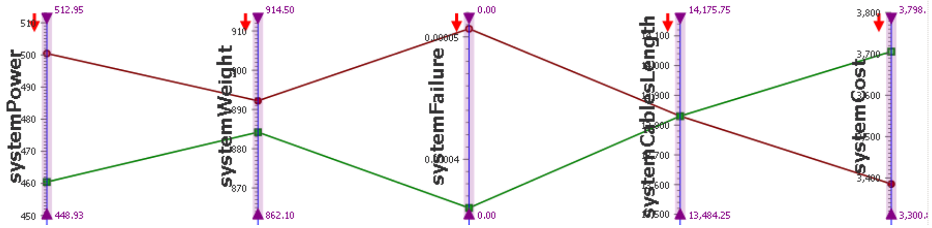
DMS: Results [2/2]

1. SysML modeling

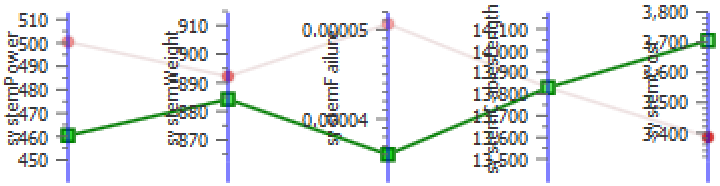


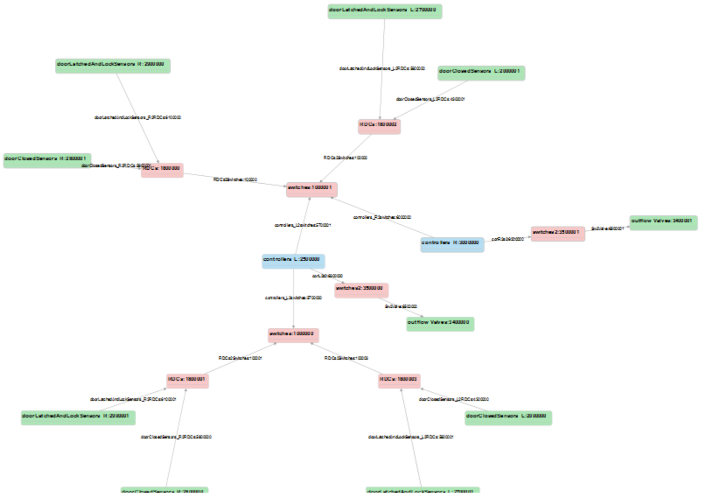
2. Run Optimization and show alternatives

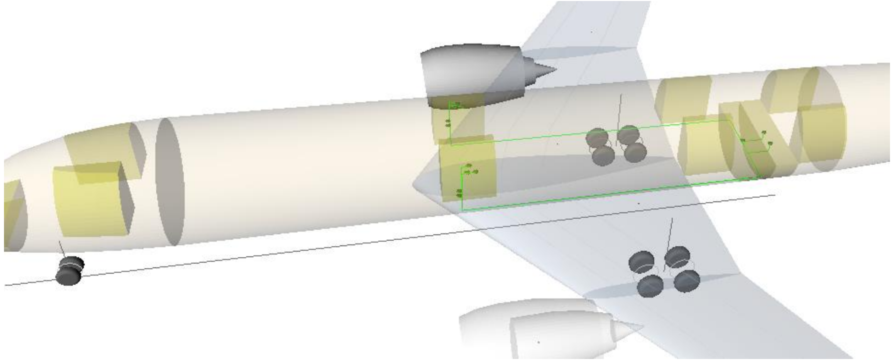
ID	systemPower	systemWeight	systemFailure	systemCablesLength	systemCost	Finished at	Duration
2ece937c-a4b9-4ac8-b0ab-702de3a1c94a	500.44	892.20	5.066E-5	13830.00	3385.50	May 23, 2013 11:14:54 AM	942 sec
3232cbf2-0383-4500-811a-52d643079cd3	460.44	884.20	3.602E-5	13830.00	3705.50	May 23, 2013 11:10:54 AM	938 sec



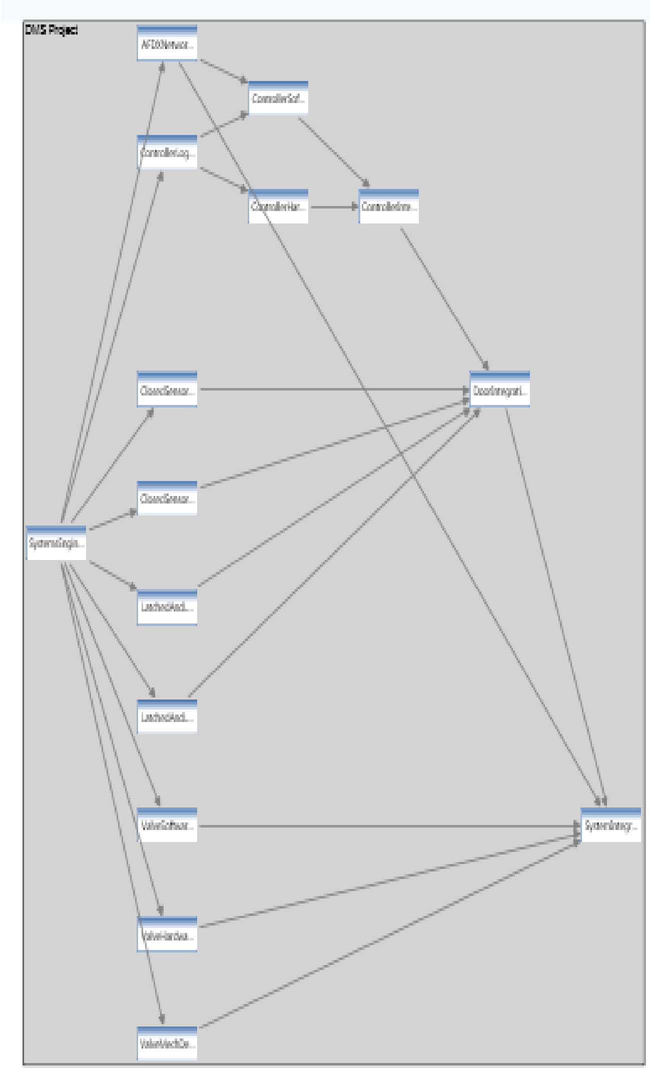
3. Visualize the alternatives

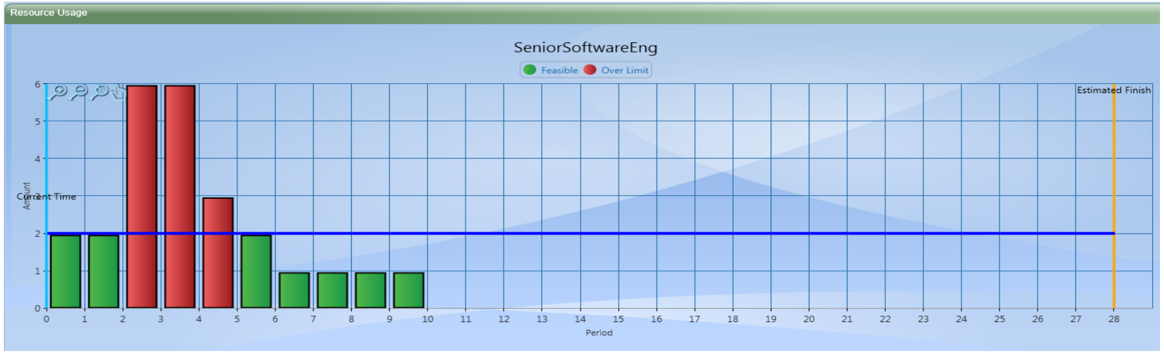




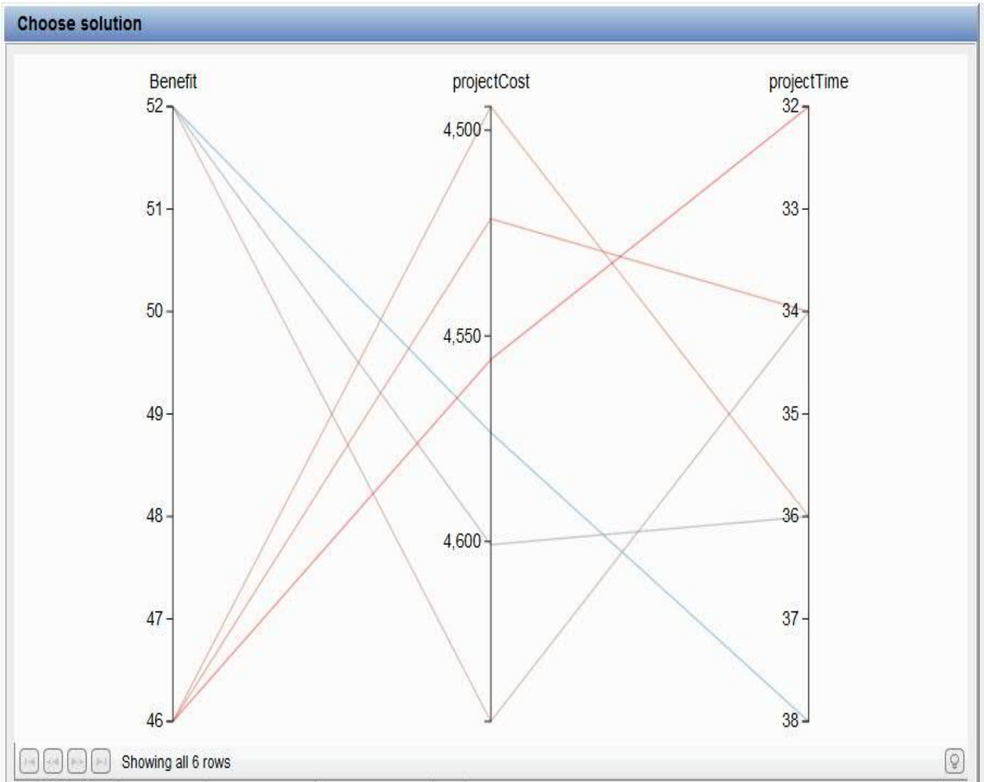


Project Team Builder (PTB) model





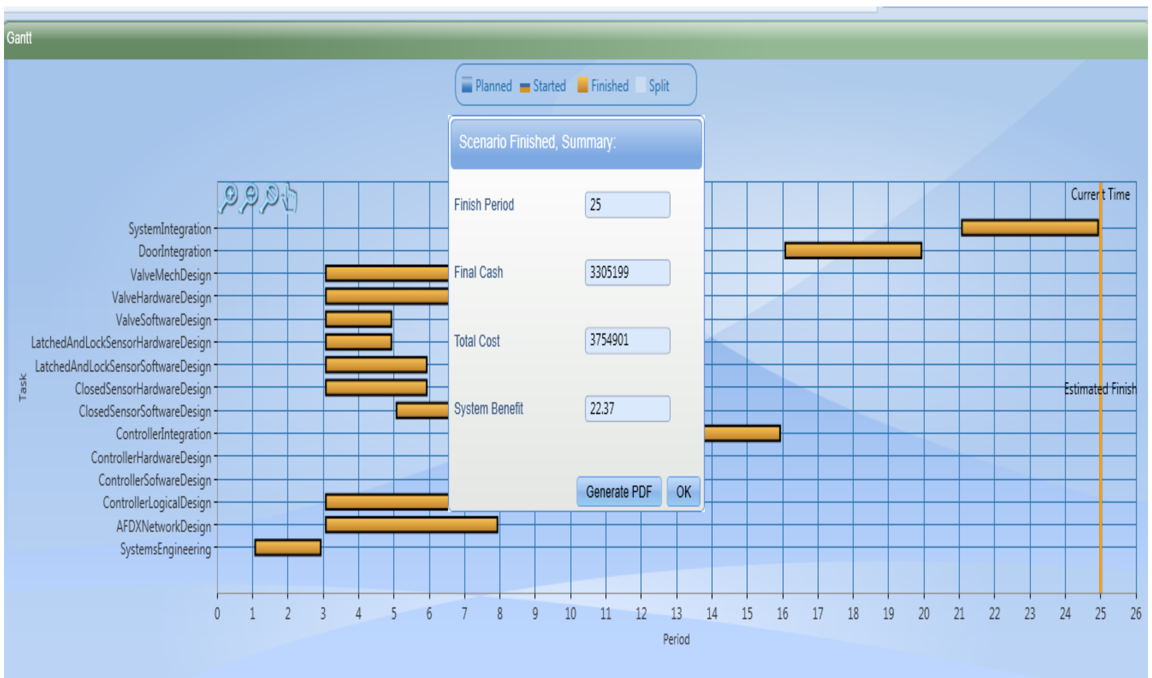
AOW – PM



iterationId	Benefit	projectCost	projectTime
1	52	4573.5	38
2	52	4600.75	36
3	52	4643.75	34
4	46	4494.25	36
5	46	4521.5	34
6	46	4555.75	32

AOW: AO-PM

iterationI...	systemW...	systemC...	systemP...	projectTi...	projectC...
1	195.3	2775.5	302.02	46	4662.5
2	195.3	2775.5	302.02	48	4635.25

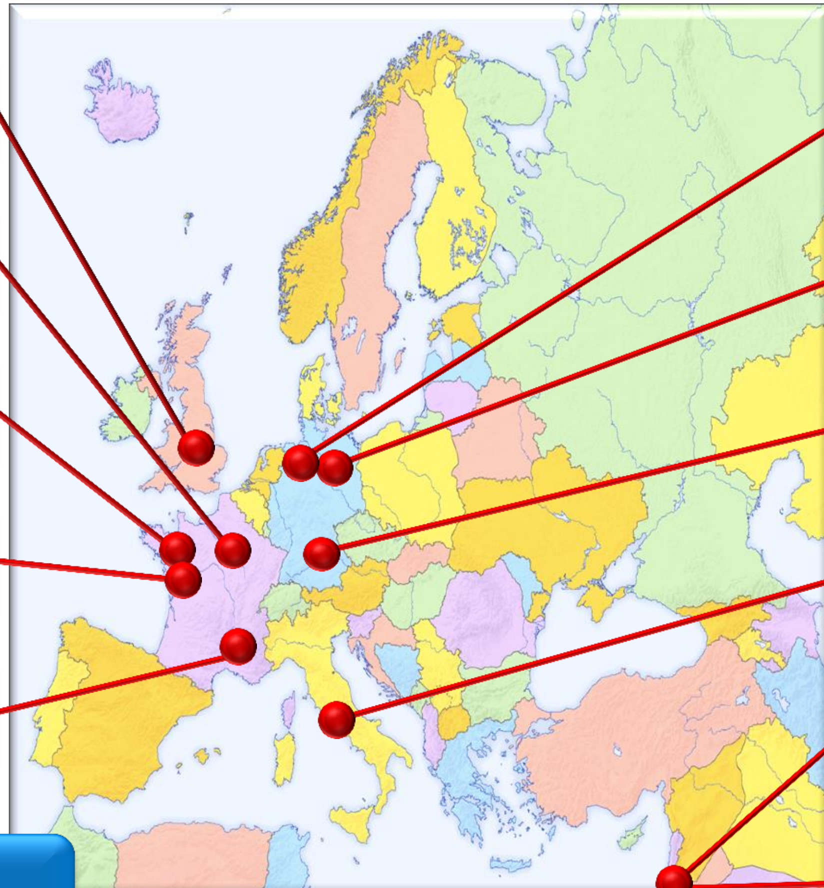


Agenda

- From SE to MBCE
- AOW background
- PORTALS
- FAME
- EMI
- **DANSE**
- Summary

DANSE: Design for Adaptability and evolutioN in System of systems Engineering

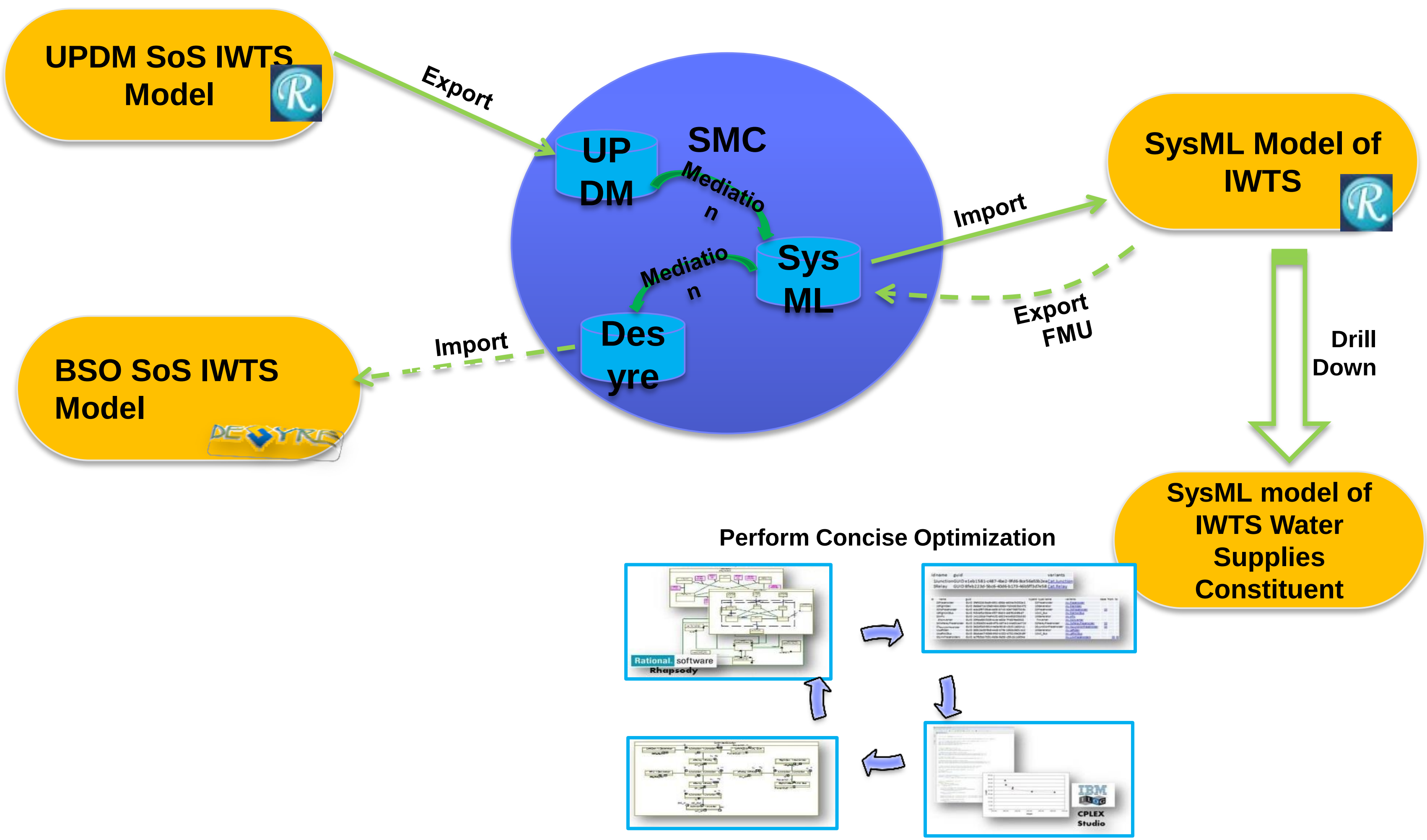
- Loughborough University
- THALES
- INRIA Rennes
- SODIUS
- Airbus France
- Honourcode (technical support)



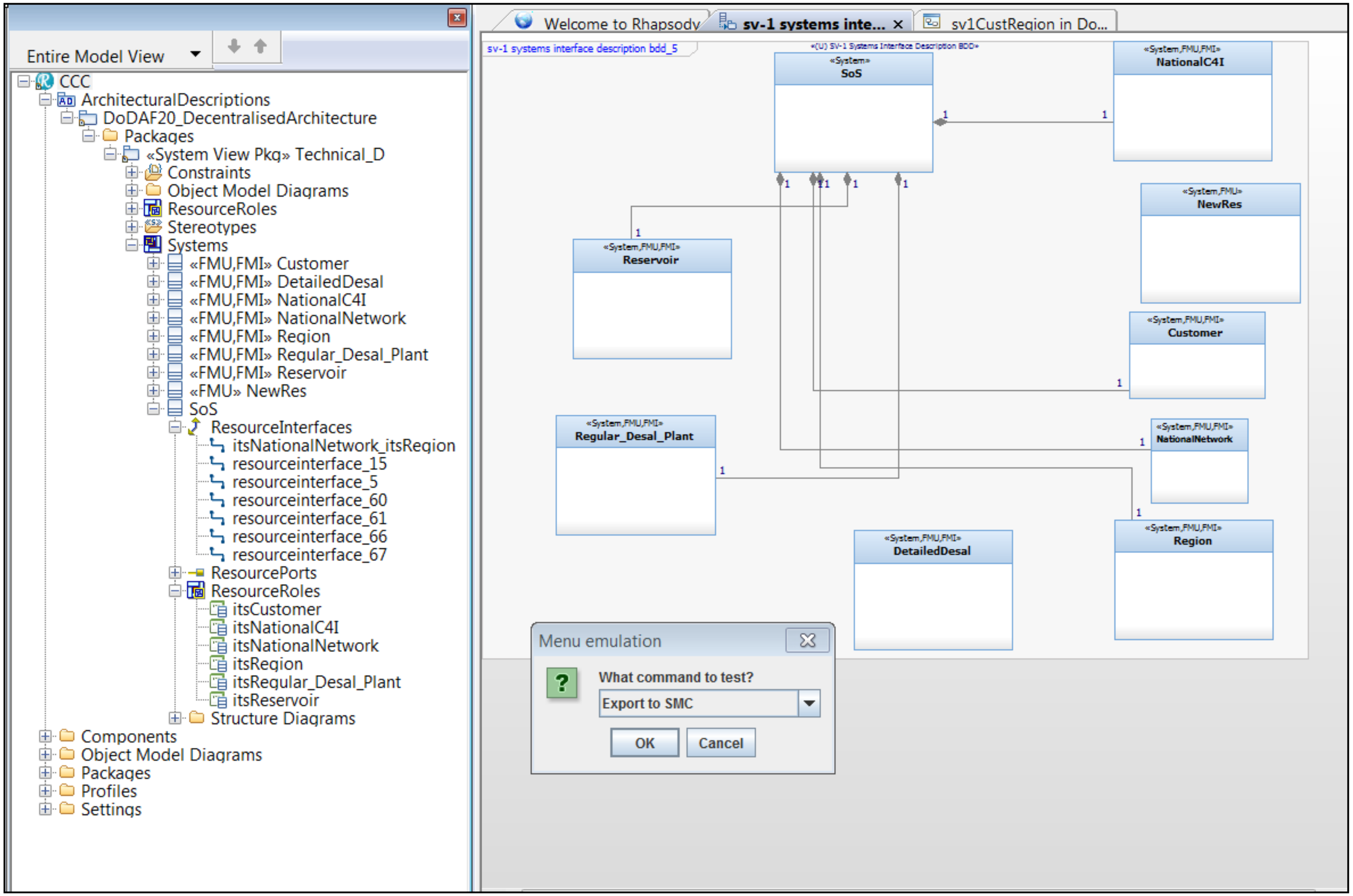
- OFFIS Co-ordinator
- Carmeq
- Airbus Germany
- Advanced Laboratory on Embedded Systems
- IBM Research - Haifa
- Israel Aerospace Industries

SEVENTH FRAMEWORK PROGRAMME

Scenario Overview

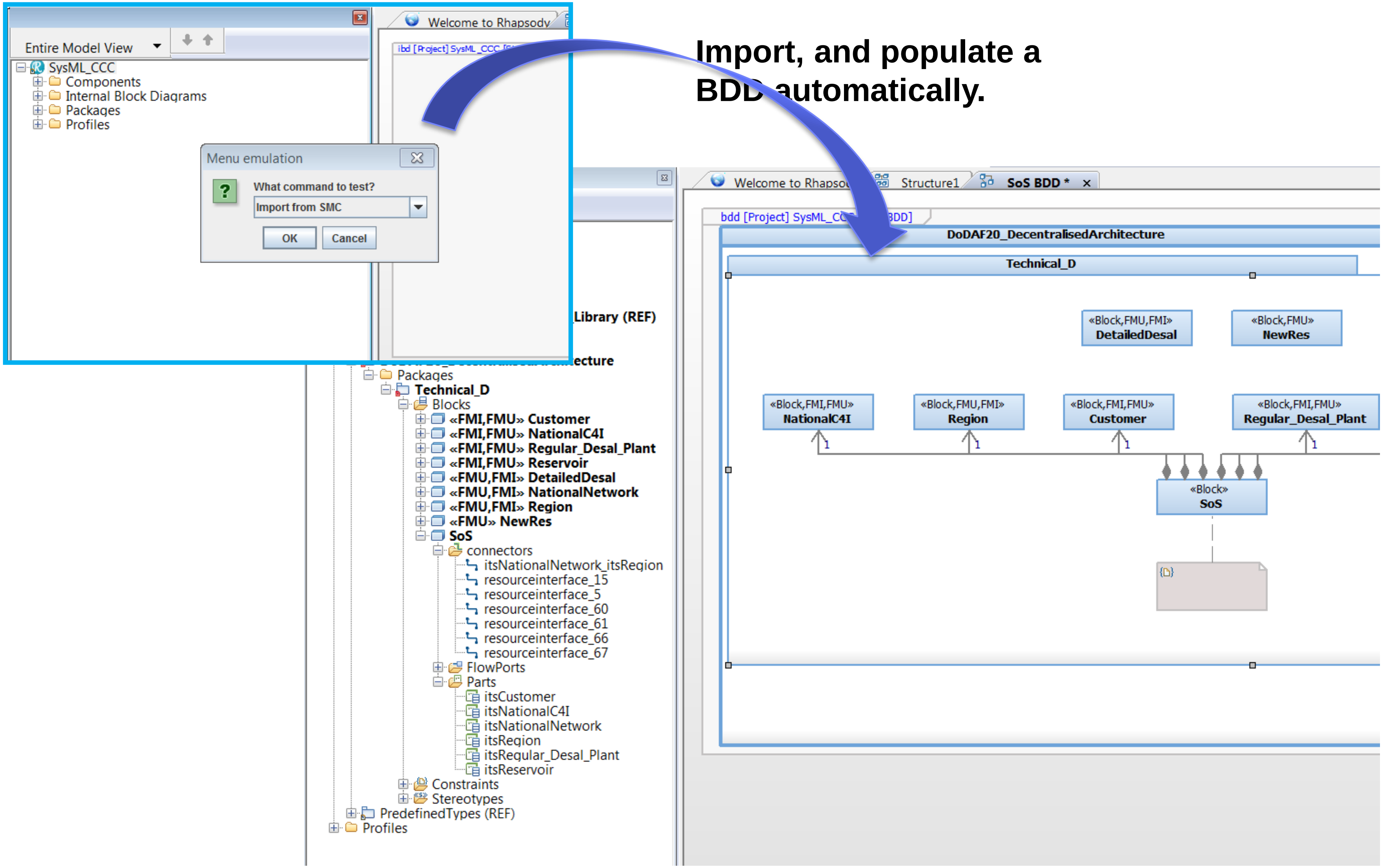


Full model (UPDM)

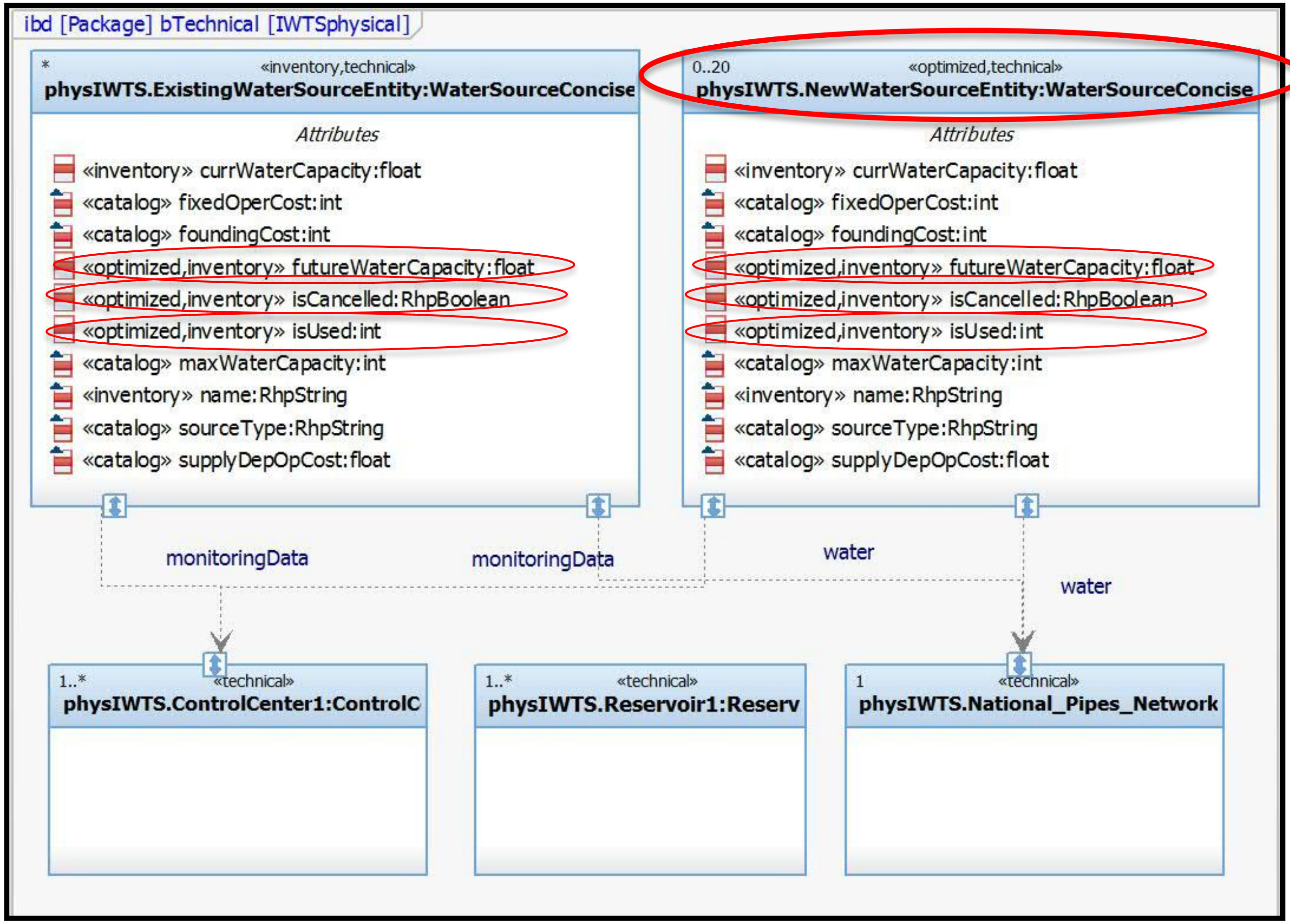


Importing to Rhapsody SysML project

Import, and populate a BDD automatically.



Decision variables



Excel tables (inventory & catalog)

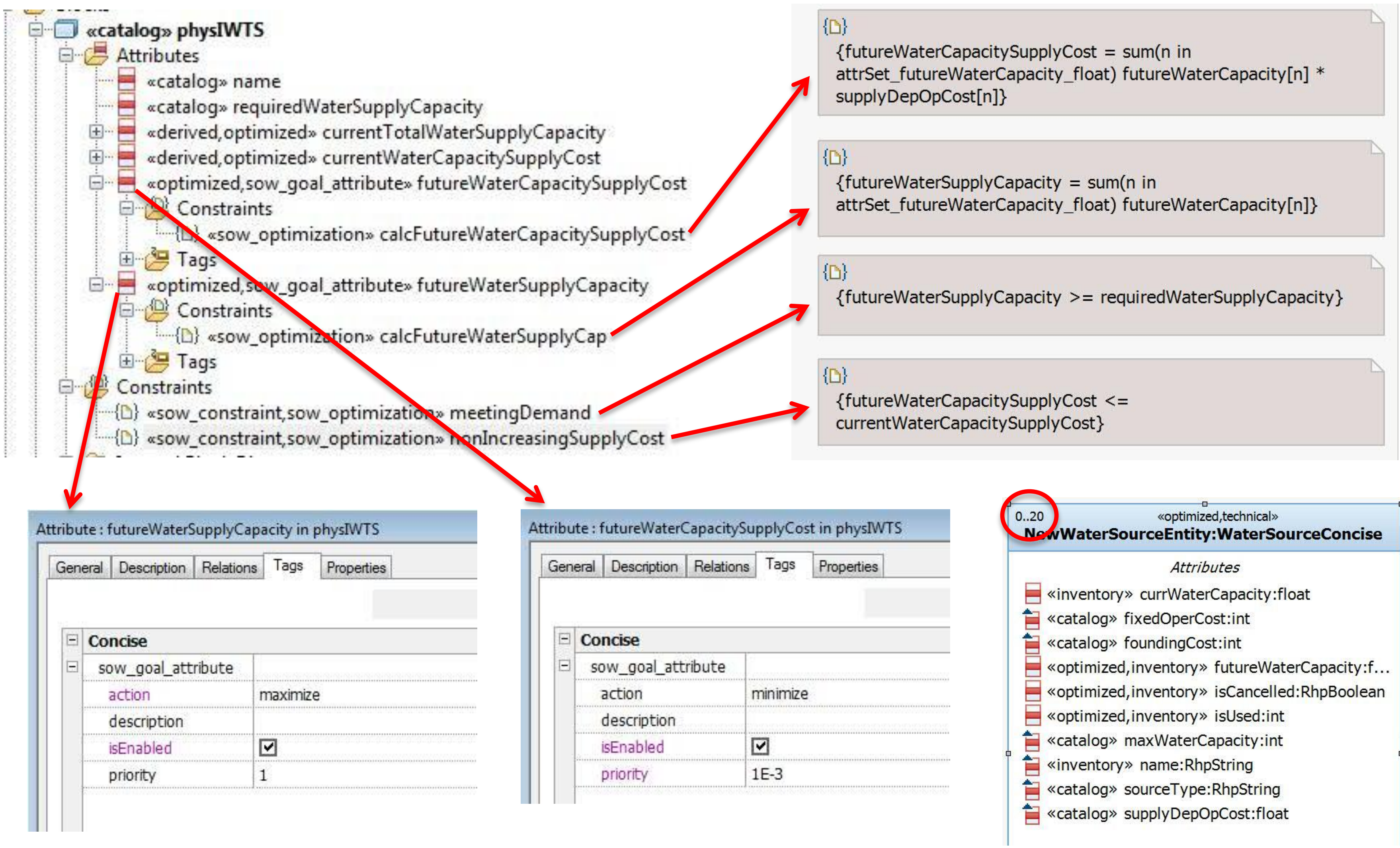
	A	B	C	D	E	F	G
1	int	int	int	int	float	RhpString	
2	id	maxWaterCapacity	foundingCost	fixedOperCost	supplyDepOpCost	sourceType	
3	1000000	10000			300	Desal_Large	
4	1000001	5000			1000	Desal_Medium	
5	1000002	6000			300	Ground_Water_Medium	
6	1000003	2500			300	Ground_Water_Small	
7	1000004	100000			100	Grand_National_Lake	
8							

Types | Instances | c_physIWTS#9 | c_WaterSourceConcise#10

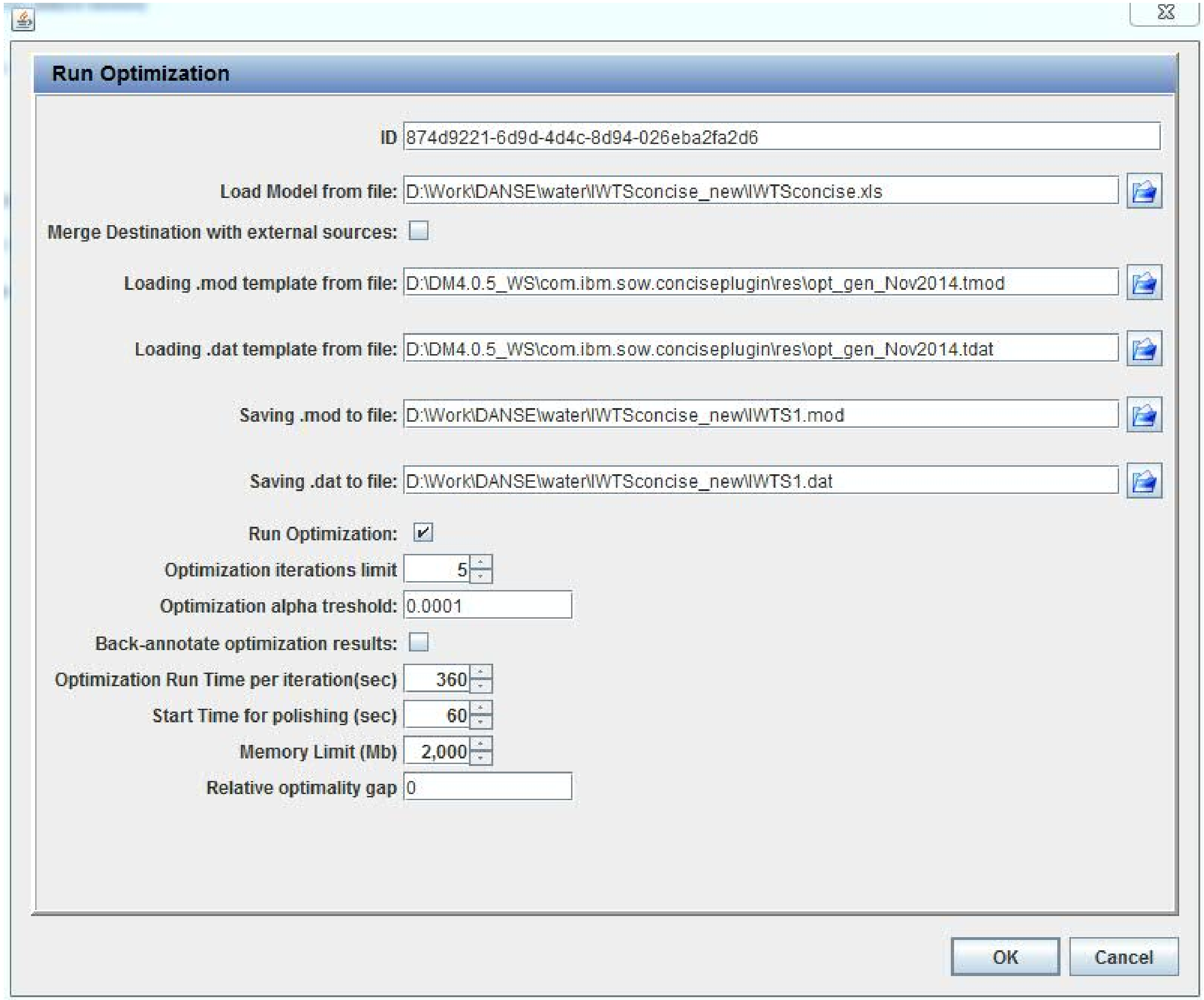
	A	B	C	D	E	F	G	H	I
1	int	int	int	int	float	float	RhpBoolean	RhpString	
2	id	owningPart	c_id	isUsed	futureWaterCapacity	currWaterCapacity	isCancelled	name	
3	1700000		1000000			2000		DesalL1	
4	1700001		1000000			2000		DesalL2	
5	1700002		1000001			1000		DesalM3	
6	1700003		1000001			2500		DesalM4	
7	1700004		1000001			5000		DesalM5	
8	1700005		1000001			500		DesalM6	
9	1700006		1000002			700		GroundM1	
10	1700007		1000002			700		GroundM2	
11	1700008		1000003			200		GroundS3	
12	1700009		1000003			2500		GroundS4	
13	1700010		1000004			70000		GrandLake1	
14									

c_WaterSourceConcise#10 | i_ExistingWaterSourceEntity#17

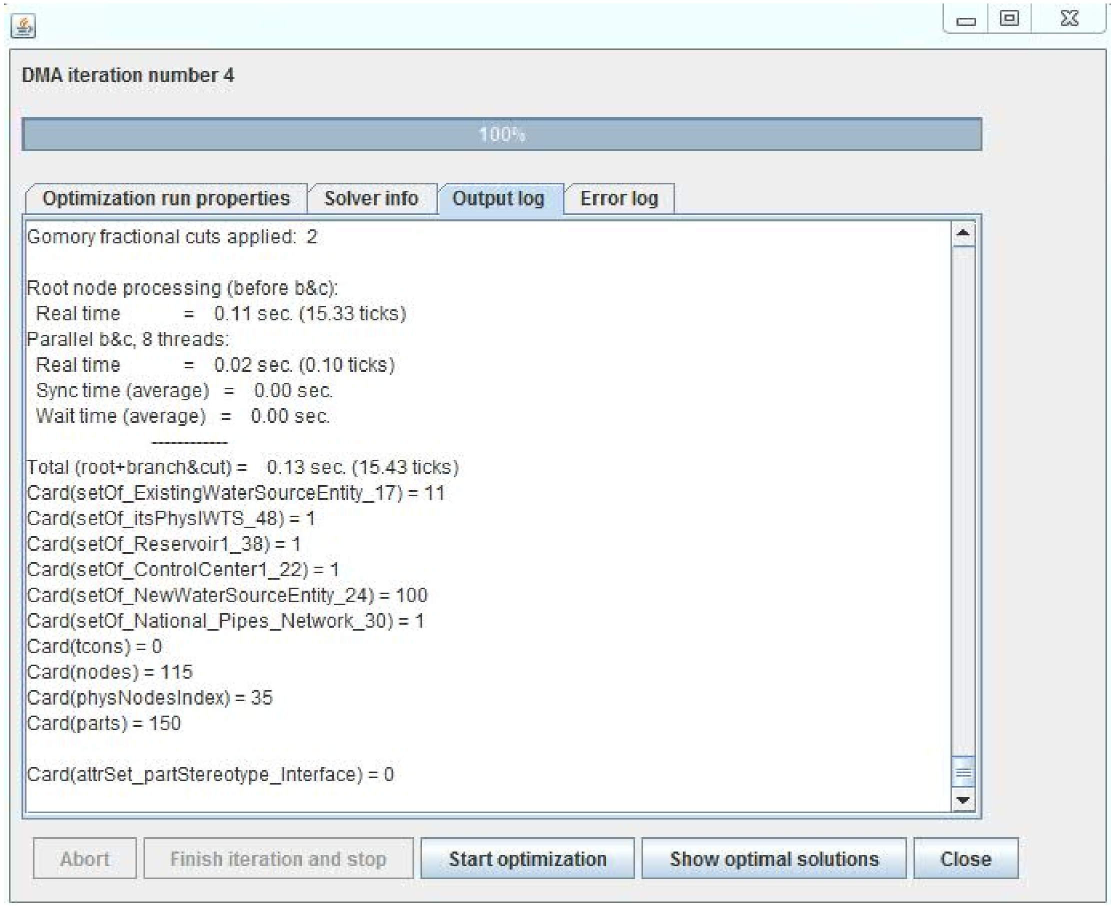
Goals and constraints



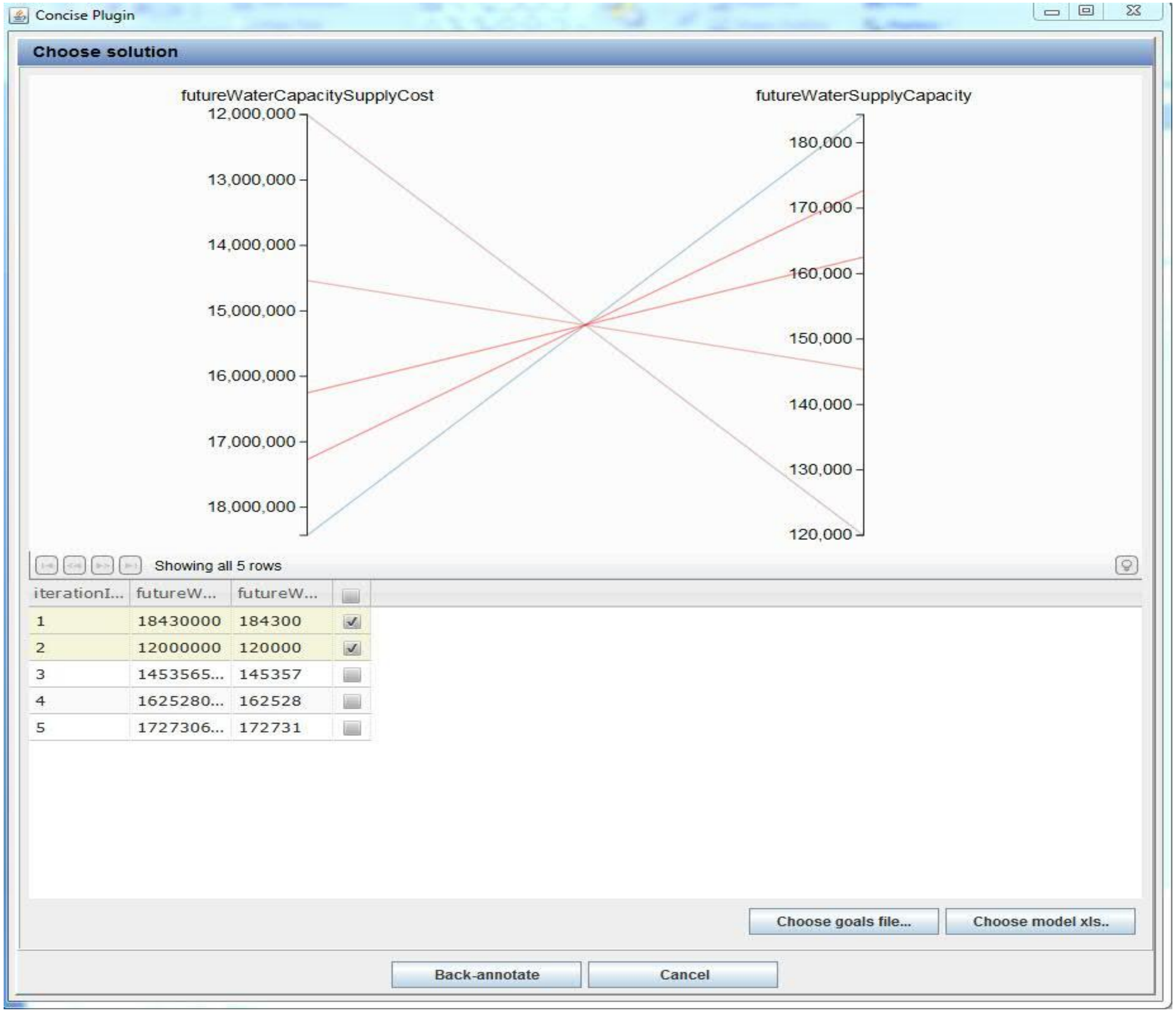
Setting optimization parameters



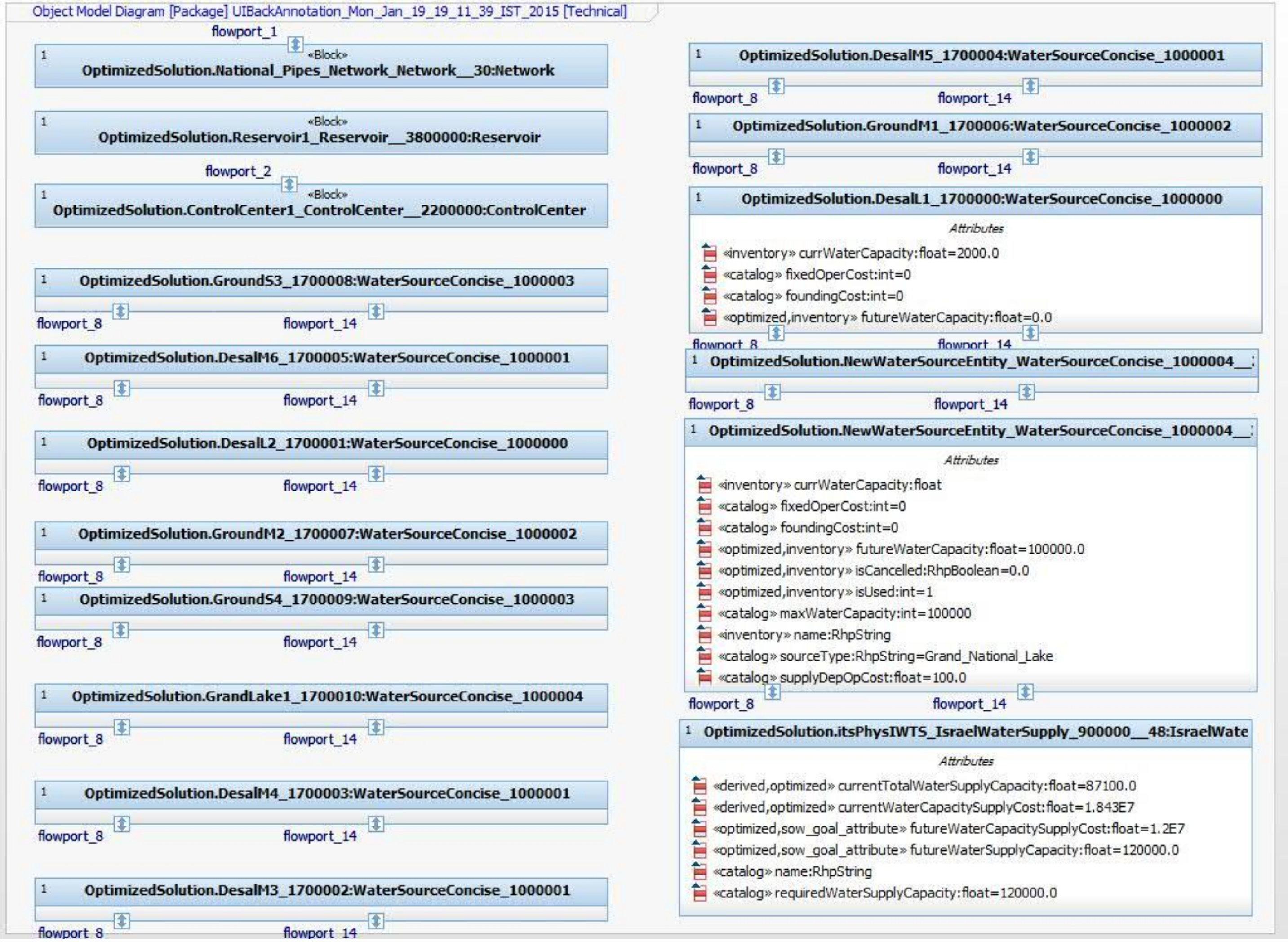
Running optimization



Snake diagram



One of optimal solutions



Agenda

- From SE to MBCE
- AOW background
- PORTALS
- FAME
- EMI
- DANSE
- **Summary**

Summary

- New paradigm – Model Based Continuous Engineering

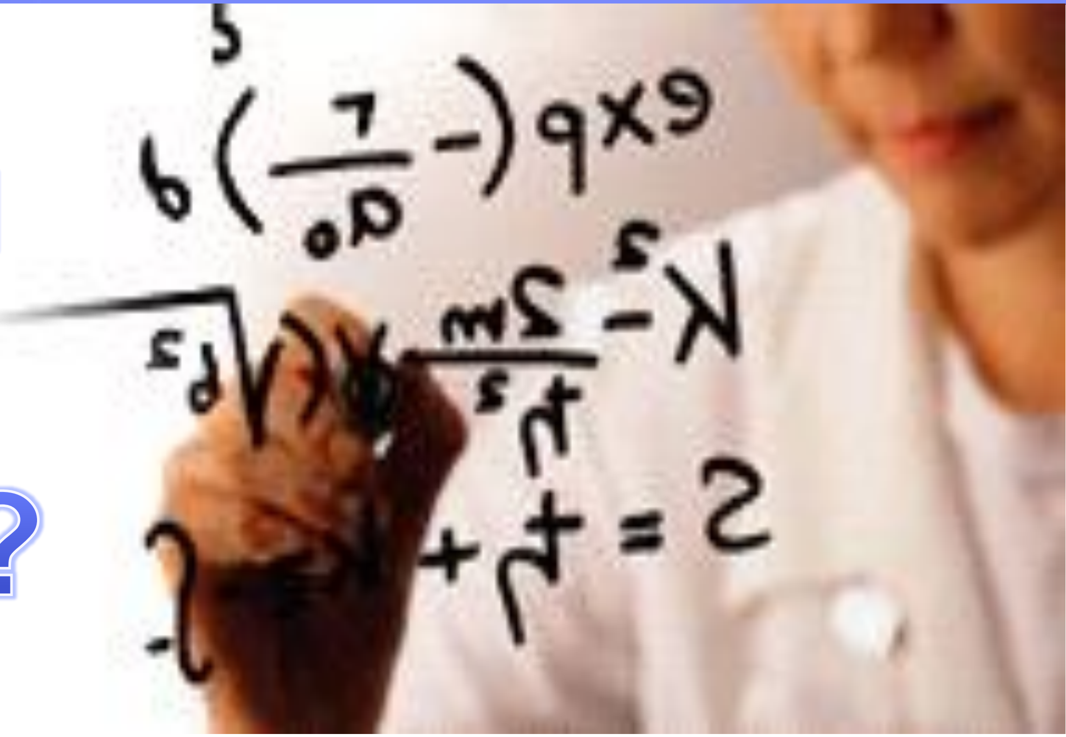
- Model generation using free and restricted input
  - support from reusable Engineering Knowledge Base is mandatory
  - reusable structural and analysis libraries

- Open World Assumption
  - Power of incompleteness – mediate what is common
  - Property based semantic middleware (SEMI)
  - Integration of external data sources, legacy tools, and operational / lifecycle data

- Ontology based concepts and property-defined sets enable building reusable libraries for lifecycle optimization and analysis
  - Current reusable libraries: mapping, reliability, resource allocation, interface compatibility, power distribution, voltage drop, data flow, total availability, lifecycle cost, project management… (ongoing extension)

Thank you

Questions?



Systems & IoT Engineering group